

**Draft Recommendation for
Space Data System Standards**

**TRACKING DATA
MESSAGE**

DRAFT RECOMMENDED STANDARD

CCSDS 503.0-R-1

RED BOOK
November 2005

AUTHORITY

Issue:	Red Book, Issue 1
Date:	November 2005
Location:	Not Applicable

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Office of Space Communication (Code M-3)
National Aeronautics and Space Administration
Washington, DC 20546, USA

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FOREWORD

(WHEN THIS RECOMMENDED STANDARD IS FINALIZED, IT WILL CONTAIN THE FOLLOWING FOREWORD:)

This document is a Recommended Standard for tracking data messages and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The tracking data message described in this Recommended Standard is the baseline concept for tracking data interchange applications that are cross-supported between Agencies of the CCSDS.

This Recommended Standard establishes a common framework and provides a common basis for the format of tracking data exchange between space agencies. It allows implementing organizations within each Agency to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance. Derived Agency standards may implement only a subset of the optional features allowed by the Recommended Standard and may incorporate features not addressed by this Recommended Standard.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, as defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

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PREFACE

This document is a draft CCSDS Recommended Standard. Its 'Red Book' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 503.0-R-1	Tracking Data Message, Draft Recommended Standard, Issue 1	November 2005	Current draft

CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION.....	1-1
1.1 PURPOSE.....	1-1
1.2 SCOPE AND APPLICABILITY	1-1
1.3 CONVENTIONS AND DEFINITIONS.....	1-2
1.4 STRUCTURE OF THIS DOCUMENT.....	1-2
1.5 REFERENCES	1-3
1.6 INFORMATION SECURITY	1-3
2 OVERVIEW	2-1
2.1 GENERAL.....	2-1
2.2 THE TRACKING DATA MESSAGE (TDM).....	2-1
2.3 EXCHANGE OF MULTIPLE TDMS / TRACKING OF MULTIPLE OBJECTS.....	2-1
3 TRACKING DATA MESSAGE STRUCTURE AND CONTENT.....	3-1
3.1 GENERAL.....	3-1
3.2 TDM HEADER	3-2
3.3 TDM METADATA	3-3
3.4 TDM DATA BLOCK (GENERAL SPECIFICATION).....	3-15
3.5 TDM DATA BLOCK KEYWORDS	3-18
4 TRACKING DATA MESSAGE SYNTAX	4-1
4.1 GENERAL.....	4-1
4.2 TDM LINES	4-1
4.3 TDM VALUES.....	4-2
4.4 UNITS IN THE TDM TRACKING DATA RECORD	4-3
4.5 COMMENTS IN A TDM.....	4-3
ANNEX A RATIONALE FOR TRACKING DATA MESSAGES (Informative).....	A-1
ANNEX B ITEMS FOR AN INTERFACE CONTROL DOCUMENT (Informative)	B-1
ANNEX C ABBREVIATIONS AND ACRONYMS (Informative).....	C-1
ANNEX D EXAMPLE TRACKING DATA MESSAGES (Informative)	D-1
ANNEX E INFORMATIVE REFERENCES (Informative)	E-1

CONTENTS (continued)

<u>Figure</u>	<u>Page</u>
D-1 TDM Example: 1-Way Data.....	D-4
D-2 TDM Example: 1-Way Data w/Frequency Offset	D-5
D-3 TDM Example: 2-Way Frequency Data for Doppler Calculation	D-6
D-4 TDM Example: 2-Way Ranging Data Only.....	D-7
D-5 TDM Example: 3-Way Frequency Data	D-8
D-6 TDM Example: 4-Way Data	D-9
D-7 TDM Example: One S/C, X-up, S-down, X-down, Ka-down, 3 Segments	D-11
D-8 TDM Example: Differenced Range Observable.....	D-12
D-9 TDM Example: Differenced Doppler Observable.....	D-13
D-10 TDM Example: Differenced Doppler Observable.....	D-14
D-11 TDM Example: delta-DOR Observable	D-15
D-12 TDM Example: Angle Data Only	D-16
D-13 TDM Example: Media Data Only.....	D-17
D-14 TDM Example: Meteorological Data Only	D-18
D-15 TDM Example: Clock Bias/Drift Only.....	D-19
D-16 TDM Example: Uplink Frequencies Only	D-20
D-17 TDM Example: Combined Doppler, Range, Angles.....	D-21
D-18 TDM Example: Two Uplinks	D-22

Table

3-1 TDM File Layout Specifications.....	3-1
3-2 TDM Header	3-3
3-3 TDM Metadata Block	3-6
3-4 Tracking Data Record Generic Format.....	3-16
3-5 Summary Table of TDM Data Block Keywords (Alpha Order).....	3-19
3-6 Summary Table of TDM Data Block Keywords (Category Order).....	3-20
A-1 Primary Requirements	A-2
A-2 Heritage Requirements.....	A-3
A-3 Desirable Characteristics	A-3
D-1 Measurement Specific Keywords and Settings.....	D-2

1 INTRODUCTION

1.1 PURPOSE

1.1.1 This Tracking Data Message (TDM) draft Recommended Standard specifies a standard message format for use in exchanging spacecraft tracking data between space Agencies. Such exchanges are used for distributing tracking data output from routine interagency cross-supports in which spacecraft missions managed by one agency are tracked from a ground station managed by a second agency. The standardization of tracking data formats facilitates space agency allocation of tracking sessions to alternate tracking resources. This draft Recommended Standard has been developed via consensus of the Navigation Working Group of the CCSDS Mission Operations and Information Management Services (MOIMS) area.

1.1.2 This document includes requirements and criteria that the message format has been designed to meet. For exchanges where these requirements do not capture the needs of the participating Agencies another mechanism may be selected.

1.2 SCOPE AND APPLICABILITY

1.2.1 This draft Recommended Standard contains the specification for a Tracking Data Message standard designed for applications involving tracking data interchange between space data systems. The rationale behind the design of the message is described in annex A and may help the application engineer construct a suitable message. It is acknowledged that this first version of the Recommended Standard may not apply to every single tracking session or data type; however, it is desired to focus on covering approximately the '95% level' of tracking scenarios, and to expand the coverage in future versions as more experience with the TDM is gained.

1.2.2 This message is suited to inter-agency exchanges that involve automated interaction. The attributes of a TDM make it primarily suitable for use in computer-to-computer communication because of the large amount of data typically present. The TDM is self-contained, with no additional information required beyond that specified in an Interface Control Document (ICD) written jointly by the service provider and customer agency.

1.2.3 Definition of the accuracy pertaining to any particular TDM is outside the scope of this draft Recommended Standard and should be specified via an Interface Control Document (ICD) between data exchange participants.

1.2.4 This draft Recommended Standard is applicable only to the message format and content, but not to its transmission. The transmission of the message between agencies is beyond the scope of this document and should be specified in the ICD. Message transmission could be based on a CCSDS data transfer protocol, file based transfer protocol such as SFTP, stream-oriented media, or other transmission mechanism. In general, the transmission mechanism must not place constraints on the technical data content of a TDM.

1.2.5 There are some specific exclusions to the TDM. The TDM specifically excludes Satellite Laser Ranging (SLR) ‘Fullrate’ and/or ‘Quicklook’ format, which are already transferred via a standardized format documented at <http://ilrs.gsfc.nasa.gov/>. Also excluded are exchanges of raw GPS data, which is standardized via the RINEX format (<http://gps.wva.net/html.common/rinex.html>). GPS navigation solutions are standardized via the SP3 format (<http://www.ngs.noaa.gov/GPS/GPS.html>).

1.2.6 Description of the message format based on the use of eXtensible Markup Language (XML) will be detailed in a future integrated XML schema document for all Navigation Data Messages (Attitude Data Messages (ADM), Orbit Data Messages (ODM), and Tracking Data Message (TDM)). See reference [E9].

1.3 CONVENTIONS AND DEFINITIONS

1.3.1 Conventions and definitions of navigation concepts such as reference frames, time systems, etc., are provided in reference [1].

1.3.2 The following conventions apply throughout this draft Recommended Standard:

- the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
- the word ‘should’ implies an optional, but desirable, specification;
- the word ‘may’ implies an optional specification;
- the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

1.4 STRUCTURE OF THIS DOCUMENT

1.4.1 Section 2 provides a brief overview of the CCSDS-recommended Tracking Data Message (TDM).

1.4.2 Section 3 provides details about the structure and content of the TDM.

1.4.3 Section 4 provides details about the syntax used in the TDM.

1.4.4 Annex A lists a set of requirements and desirable characteristics that were taken into consideration in the design of the TDM.

1.4.5 Annex B lists a number of items that should be covered in interagency ICDs prior to exchanging TDMs on a regular basis. There are several statements throughout the document that refer to the desirability or necessity of such a document; this annex consolidates all the suggested ICD items in a single list in the document.

1.4.6 Annex C is a list of abbreviations and acronyms applicable to the TDM.

1.4.7 Annex D shows how various tracking scenarios can be accommodated via the TDM, via several examples.

1.4.8 Annex E contains a list of informative references.

1.5 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this draft Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this draft Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

- [1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-2. Green Book. Issue 2. Washington, D.C.: CCSDS, November 2005.
- [2] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998.
- [3] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, January 2002.
- [4] *Orbit Data Messages*. Recommendation for Space Data System Standards, CCSDS 502.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2004.
- [5] *Spacewarn Bulletin*. Greenbelt, MD, USA: WDC-SI. <<http://nssdc.gsfc.nasa.gov/spacewarn>>.

NOTE — Informative references are provided in annex E.

1.6 INFORMATION SECURITY

Navigation Data Messages (including the ODM, ADM and TDM) may require moderate security measures to protect the data from unauthorized access. Protection from unauthorized access is especially important if the mission utilizes open ground networks such as the Internet to provide ground station connectivity for the exchange of Navigation Data Messages. In order to provide requisite security, it is recommended that Navigation Data Messages be transferred between participants via Secure FTP (SFTP), real-time authentication such as that incorporated in the Real-Time Radio-Metric Data Transfer Service (RRMDT), or other secure mechanisms approved by the IT Security functionaries of exchange participants. As noted elsewhere in this document, this document does not deal specifically with the means of transferring Navigation Data Messages, focusing rather on message content. Specific information-security provisions that may apply between agencies involved in an exchange should be specified in an ICD.

2 OVERVIEW

2.1 GENERAL

This section provides a high-level overview of the CCSDS recommended Tracking Data Message, a message format designed to facilitate standardized exchange of spacecraft tracking data between space agencies.

The Tracking Data Message in this version of the draft Recommended Standard is ASCII-text formatted. While binary-based tracking data message formats are computer efficient and minimize overhead during data transfer, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, ASCII format character-based tracking data representations are useful in transferring text files between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text files or objects to displays, emails, documents or printers are possible without preprocessing. The penalty for this convenience is some measure of inefficiency. Description of the message formats based on XML will be detailed in a future integrated XML schema document for all Navigation Data Messages (reference [E9]).

2.2 THE TRACKING DATA MESSAGE (TDM)

To aid in precision trajectory modeling, additional ancillary information may be included within a TDM if it is desired and/or available (e.g., meteorological data or tropospheric data). There are keywords in the TDM grammar that may be used to add such ancillary information.

2.3 EXCHANGE OF MULTIPLE TDMS / TRACKING OF MULTIPLE OBJECTS

2.3.1 Normally a TDM will contain tracking data for a single spacecraft participant. If a tracking operation involves information from multiple spacecraft participants, the data may be included in a single TDM; or multiple TDM files may be used, one per spacecraft participant.

2.3.2 For a given spacecraft participant, multiple tracking data messages may be provided in a message exchange session to achieve the tracking data requirements of the participating agencies (e.g., launch supports with periodically delivered TDMS, or other critical events such as maneuvers, encounters, etc.).

2.3.3 Provisions for these and other special types of exchanges should be specified in an ICD.

3 TRACKING DATA MESSAGE STRUCTURE AND CONTENT

3.1 GENERAL

3.1.1 The TDM shall be a digital file comprised of plain ASCII text lines (see reference [2]) in KVN format (Keyword = Value Notation—see section 4). The file constituting a TDM shall be represented as a combination of:

- a) a header (see 3.1.3);
- b) metadata (data about data) (see 3.3);
- c) tracking data (see 3.4); and
- d) optional comments (see 4.5).

3.1.2 Each TDM shall have a set of minimum required sections; some sections may be repeated, as shown in table 3-1. Each Metadata block must be accompanied by a minimum of one Tracking Data Record. Taken together, the metadata block and its associated Tracking Data Record(s) shall be called a TDM segment. The TDM Body shall consist of one or more TDM Segments.¹ Therefore, the overall structure of the TDM shall be:

- TDM = Header + Body
- Body = Segment [+ Segment + ... + Segment]
- Segment = Metadata + Data

Table 3-1: TDM File Layout Specifications

Item			Obligatory?
Header			Yes
Body	Segment 1	Meta 1	Yes
		Data 1	
	Segment 2	Meta 2	No
		Data 2	
	.	.	.
		.	
	Segment n	Meta n	No
		Data n	

¹ The 'segment' and 'body' concepts are introduced here in preparation for the upcoming XML implementation.

3.1.3 The TDM shall be a text file consisting of tracking data for a single tracking participant, or for multiple tracking participants, at multiple epochs contained within a specified time range. (Note that the term ‘participant’ applies equally to spacecraft, tracking stations, and agency centers, as discussed in reference [1]. Thus there may exist Tracking Data Messages for which there is no applicable spacecraft.) Generally, but not necessarily, the time range of a TDM may correspond to a ‘tracking pass’.

3.1.4 The TDM shall be easily readable by both humans and computers.

3.1.5 It shall be possible to exchange a TDM either as a real-time stream or as a file.

3.1.6 The TDM file naming scheme shall be agreed to on a case-by-case basis between the participating agencies, typically specified in an ICD. In general, the file name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies for processing tracking data.

3.1.7 The method of exchanging TDMs shall be decided on a case-by-case basis by the participating agencies and documented in an ICD.

3.2 TDM HEADER

3.2.1 The TDM shall include a Header that consists of information that identifies the basic parameters of the message. The first Header line must be the first non-blank line in the file.

3.2.2 A description of TDM Header items and values is provided in table 3-2, which specifies for each item:

- the keyword to be used,
- a short description of the item,
- examples of allowed values, and
- whether the item is obligatory or not obligatory.

3.2.3 Only those keywords shown in table 3-2 shall be used in a TDM Header. The order of occurrence of the obligatory KVN assignments shall be fixed as shown in table 3-2.

Table 3-2: TDM Header

Keyword	Description	Examples	Obligatory
CCSDS_TDM_VERS	Format version in the form of 'x.y', where 'y' shall be incremented for corrections and minor changes, and 'x' shall be incremented for major changes.	1.0 0.12 (for testing)	Yes
CREATION_DATE	File creation date/time in one of following formats: YYYY-MM-DDThh:mm:ss[.d→d][Z] or YYYY-DDDThh:mm:ss[.d→d][Z] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There is no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields require leading zeros.	2001-11-06T11:17:33 2002-204T15:56:23.4	Yes
ORIGINATOR	Creating agency. Value should be specified in the ICD.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes
COMMENT	See 4.5.	COMMENT This is a comment	No

3.2.4 The TDM Header shall provide a CCSDS Tracking Data Message version number that identifies the format version; this is included to anticipate future changes and to provide the ability to extend the standard with no disruption to existing users. The version keyword is CCSDS_TDM_VERS and the value shall have the form of x.y where y is incremented for corrections and minor changes, and x is incremented for major changes. Version 1.0 shall be reserved for the initial version accepted by the CCSDS as an official Recommended Standard ('Blue Book'). Interagency testing of TDMs shall be conducted using version numbers less than 1.0 (e.g., '0.y'). Specific TDM versions that will be exchanged between agencies should be documented via the ICD.

3.2.5 The TDM File Header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the file was created, as specified in reference [3] (ASCII Time Code A or B).

3.3 TDM METADATA

3.3.1 GENERAL

3.3.1.1 The TDM shall include at least one Metadata block that contains configuration details (metadata) applicable to the set of Tracking Data Records in the same segment. The

information in the Metadata block aligns with the tracking data to provide descriptive information (typically, the metadata is the type of information that does not change frequently).

3.3.1.2 A single TDM Metadata block shall precede each block of Tracking Data Records.

3.3.1.3 When there are changes in the values assigned to any of the keywords in the Metadata block, a new segment must be started (e.g., mode change from one-way to two-way tracking).

3.3.1.4 The first and last lines of a TDM metadata block shall consist of the META_START and META_STOP keywords, respectively. These keywords are used to facilitate file parsing.

3.3.1.5 Table 3-3 specifies for each Metadata item:

- the keyword to be used;
- a short description of the item;
- examples of allowed values; and
- whether the item is obligatory or not obligatory.

3.3.1.6 Only those keywords shown in table 3-3 shall be used in a TDM Metadata block. Obligatory items shall appear in every TDM Metadata block. Items that are not obligatory may or may not appear in any given TDM Metadata block, at the discretion of the file originator, based on the requirements of the data and its intended application. For most metadata keywords there is no default value; where there is a default value, it is specified at the end of the ‘Description’ section for the given keyword. If a keyword is not present in a TDM, the default shall be assumed where applicable.

3.3.1.7 The order of occurrence of the obligatory and optional KVN assignments shall be fixed as shown in table 3-3.

3.3.1.8 The Metadata block shall describe the participants in a tracking session using the keyword ‘PARTICIPANT_n’. There may be several participants associated with a tracking data session (the number of participants is generally greater than or equal to two). The ‘n’ in the keyword is an indexer. The indexer shall not be the same for any two participants in the same metadata block.

3.3.1.9 The value associated with any given PARTICIPANT_n keyword may be a ground tracking station, a spacecraft, a quasar catalog name; or may include non-traditional objects, such as landers, rovers, balloons, etc. The list of eligible names that is used to specify participants should be documented in the ICD. Subsections 3.3.2 through 3.3.9 provide an explanation of the tracking modes and participant numbers.

3.3.1.10 Participants may generally be listed in any order; however, there are some exceptions in which a specific convention must be observed with respect to the order in which the participants are listed (exceptions noted in table 3-3 and subsection 3.3.7).

3.3.1.11 In this version of the TDM, the maximum number of participants per segment shall be five. If more than five participants are defined (i.e., PARTICIPANT_6 +), then special arrangements are necessary. These arrangements should be documented in an ICD. Note that although the restriction to five participants may appear to be a constraint, it is probably not, because of other aspects of the TDM structure. Five participants easily allow the user to describe the great majority of tracking passes. In some cases there may be ‘critical event’ tracking sessions in which a single spacecraft is tracked by a large number of antennas, such that the total number of participants appears to be six or more. However, because of the nature of the ‘PATH’ keyword, several TDM segments would be required to describe the full set of tracking data. Even if a ‘PATH’ statement could be contrived to cover such a case, there would likely be violations of the ‘keyword/timetag uniqueness’ restriction.

Table 3-3: TDM Metadata Block

Keyword	Description	Examples	Obligatory
META_START	The META_START keyword shall delineate the start of the TDM Metadata block within the message. It must appear on a line by itself.	N/A	Yes
COMMENT	See 4.5. Note that if comments are used in the metadata, they shall only appear at the beginning of the metadata section.	N/A	No
TIME_SYSTEM	The TIME_SYSTEM keyword shall specify the time system used for timetags in the associated Tracking Data Records. This should be UTC for ground-based data. The allowed values are the same as in the ODM, but also may include a local spacecraft clock, as applicable. See references [1] and [4].	UTC, TAI, GPS, SCLK	Yes
PARTICIPANT_n n = {1, 2, 3, 4, 5}	The PARTICIPANT_n keyword shall represent the participants in a tracking data session. It is indexed to allow unambiguous reference to other data in the TDM (max index is 5). At least two participants must be specified for most sessions; for some special TDMs such as media only or clock bias only, only one participant need be listed. Participants may include ground stations, spacecraft, and/or quasars. Participants represent the classical transmitting parties, transponding parties, and receiving parties, while allowing for flexibility to consider tracking sessions that go beyond the familiar one-way spacecraft-to-ground, two-way ground-spacecraft-ground, etc. For MODE='SINGLE-DIFF' or 'DOUBLE-DIFF', the order in which participants are listed is important. See 3.3.7 below for details of the ordering. For mode='SEQUENTIAL', participants may be listed in any order, and the PATH keyword specifies the signal path. For spacecraft identifiers, there is no CCSDS-based restriction on the value for this keyword, but names could be drawn from the SPACEWARN Bulletin (reference [5]), which includes Object name and international designator of the participant. The list of eligible names that is used to specify participants should be documented in the ICD.	DSS-63-S400K ROSETTA <Quasar catalog name> 1997-061A	Yes

Keyword	Description	Examples	Obligatory
MODE	The MODE keyword shall reflect the tracking mode associated with the data portion of the segment. This keyword must have a value from the set at right. If the actual value is not known, the best hypothesis shall be provided. Use of this keyword is conditional: it applies only for range, Doppler, and differenced data. Other cases, such as transmit only, media, weather, etc., use 'N/A' as the MODE setting.	SEQUENTIAL SINGLE-DIFF DOUBLE-DIFF N/A	Yes
PATH	The PATH keyword shall reflect the signal path by listing the index of each participant in order, separated by commas. The first entry in the PATH shall be the transmit participant. This keyword is applicable only if the MODE is SEQUENTIAL (i.e., MODE=SEQUENTIAL is specified). The integers 1, 2, 3, 4, 5 correlate with the indexer of the PARTICIPANT keyword. Examples: 1,2 = one-way; 2,1,2 = two-way; 3,2,1 = three-way; 1,2,3,4 = four-way. The default value shall be 'N/A'.	1, 2, 1 1, 2, 4, 3 N/A	No
DIFF_MODE	The DIFF_MODE keyword is required only if the MODE is SINGLE-DIFF or DOUBLE-DIFF. 'DELAY' shall be used if the differenced observable is a time value, and 'RANGE' shall be used if the observable is a distance value. The default value shall be 'N/A'.	DELAY RANGE N/A	No
TIMETAG_REF	The TIMETAG_REF keyword shall provide a reference for downlink time tags in the tracking data. This keyword must have a value from the set at right, which indicates whether the timetag associated with the downlink data is the transmit time or the receive time. The default value shall be 'RECEIVE'. NOTE – For uplink data, the timetag always represents the transmit time, so TIMETAG_REF need not be specified.	TRANSMIT RECEIVE	No
INTEGRATION_INTERVAL	The INTEGRATION_INTERVAL keyword shall provide the Doppler count time in seconds for Doppler data or for the creation of normal points (also applicable for differenced Doppler; also sometimes known as 'compression time', 'condensation interval', etc.). The data type shall be positive double precision. The default value shall be 1.0.	60.0 0.1	No

Keyword	Description	Examples	Obligatory
INTEGRATION_REF	The INTEGRATION_REF keyword shall be used in conjunction with the TIMETAG_REF and INTEGRATION_INTERVAL keywords. This keyword must have a value from the set at right, which indicates the relationship between the INTEGRATION_INTERVAL and the timetag on the data, i.e., whether the timetag represents the start, middle or end of the integration period. The default value shall be MIDDLE.	START MIDDLE END	No
FREQ_OFFSET	The FREQ_OFFSET keyword represents a frequency that must be added to every RECEIVE_FREQ to reconstruct it; used if the Doppler observable is transferred instead of the RECEIVE_FREQ. The data type shall be double precision. The default shall be 0.0 (zero).	0.0 8415000000.0	No
RANGE_MODE	The RANGE_MODE keyword must have a value from the set at right. The value of the RANGE_MODE shall be 'COHERENT', in which case the range tones are coherent with the uplink carrier, and the range unit must be defined in an ICD, or 'CONSTANT', in which case the range tones have a constant frequency. The default value shall be 'COHERENT'. NOTE – It cannot be determined in advance whether the range mode is coherent or non-coherent. For ESA and JAXA, it is important for the two/three-way Doppler to be coherent, but not the RANGE. This keyword may not be applicable for differenced range data.	COHERENT CONSTANT	No
RANGE_MODULUS	The value associated with the RANGE_MODULUS keyword shall be the modulus of the range observable, i.e., the actual (unambiguous) range is an integer k times the modulus, plus the observable value. RANGE_MODULUS shall be a positive double precision value (normally integer for range, but can be non-integer for differenced range). For measurements that are not ambiguous range, the MODULUS setting shall be 0 to indicate an essentially infinite modulus. The default value shall be 0.0.	32768.0 2.0e+23 0.0 161.6484	No
RANGE_UNITS	The RANGE_UNITS keyword specifies the units for the range observable and range rate. 'RU', for 'range units', shall be used where the transmit frequency is changing. 'S', for 'seconds', shall be used where the transmit frequency is constant. 'KM' shall be used if the range is measured in kilometers. The default value shall be 'S'.	RU S KM	No

Keyword	Description	Examples	Obligatory
ANGLE_TYPE	<p>The ANGLE_TYPE keyword shall indicate the type of antenna geometry represented in the angle data (ANGLE_1 and ANGLE_2 keywords). The value should generally be one of the values from the set at right:</p> <ul style="list-style-type: none"> – RADEC for right ascension, declination or hour angle, declination (needs to be referenced to inertial frame); – AZEL for azimuth, elevation (local horizontal); – XEYN for x-east, y-north; – XSYE for x-south, y-east. <p>Other values are possible, but should be defined in ICD. The default value shall be 'N/A'.</p>	RADEC AZEL XEYN XSYE N/A	No
REFERENCE_FRAME	<p>The REFERENCE_FRAME keyword shall be used in conjunction with the 'ANGLE_TYPE=RADEC' keyword/value combination, indicating the inertial reference frame to which the antenna frame is referenced. Applies only to ANGLE_TYPE = RADEC. The default value shall be 'N/A'.</p>	J2000 N/A	No
TRANSMIT_DELAY_n n = {1, 2, 3, 4, 5}	<p>The TRANSMIT_DELAY_n keyword shall specify a fixed delay in seconds that should be added to each TRANSMIT timetag to account for antennas with remote electronics, arraying delays, or spacecraft transponder delays. The 'n' corresponds to the 'n' associated with the PARTICIPANT keyword (i.e., TRANSMIT_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with uplink antenna arraying should be indicated with this keyword. Transponder delays (e.g., for spacecraft-spacecraft ranging) should be specified via the TRANSMIT_DELAY_n and RECEIVE_DELAY_n keywords. The TRANSMIT_DELAY shall be a positive double precision value. The default value shall be 0.0.</p> <p>NOTE – This value is different from the 'CLOCK_BIAS' keyword in the Tracking Data Records keywords.</p>	1.23 .0326 .00077	No

Keyword	Description	Examples	Obligatory
RECEIVE_DELAY_n n = {1, 2, 3, 4, 5}	<p>The RECEIVE_DELAY_n keyword shall specify a fixed delay in seconds that should be subtracted from each RECEIVE timetag to account for antennas with remote electronics, arraying delays, or spacecraft transponder delays. The 'n' corresponds to the 'n' associated with the PARTICIPANT keyword (i.e., RECEIVE_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with downlink antenna arraying should be indicated with this keyword. Transponder delays (e.g., for spacecraft-spacecraft ranging) should be specified via the TRANSMIT_DELAY_n and RECEIVE_DELAY_n keywords. The RECEIVE_DELAY shall be a positive double precision value. The default value shall be 0.0.</p> <p>NOTE – This value is different than the 'CLOCK_BIAS' keyword in the Tracking Data Records keywords.</p>	<p>1.23 .0326 .00777</p>	No
START_TIME	<p>The START_TIME keyword shall specify the start time of total time span covered by tracking data immediately following this metadata block, in one of the two following formats: YYYY-MM-DDThh:mm:ss[.d→d][Z] or YYYY-DDDThh:mm:ss[.d→d][Z] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There shall be no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields shall have leading zeros.</p>	<p>1996-12-18T14:28:15.1172 1996-277T07:22:54</p>	Yes
STOP_TIME	<p>The STOP_TIME keyword shall specify the stop time of total time span covered by tracking data immediately following this metadata block, in one of the two following formats: YYYY-MM-DDThh:mm:ss[.d→d][Z] or YYYY-DDDThh:mm:ss[.d→d][Z] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There shall be no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields shall have leading zeros.</p>	<p>1996-12-18T14:28:15.1172 1996-277T07:22:54</p>	Yes

DRAFT CCSDS RECOMMENDED STANDARD FOR TRACKING DATA MESSAGE

Keyword	Description	Examples	Obligatory
DATA_QUALITY	<p>The DATA_QUALITY keyword may be used to provide an estimate of the quality of the data, based on indicators from the producers of the data (e.g., bad time synchronization flags, marginal lock status indicators, etc.). A value of 'RAW' shall indicate that no quality check of the data has occurred (e.g., in a real time broadcast or near real time automated file transfer). A value of 'VALIDATED' shall indicate that data quality has been checked, and passed tests. A value of 'DEGRADED' shall indicate that data quality has been checked and quality issues exist. 'Checking' may be via human intervention or automation. Specific definitions of 'RAW', 'VALIDATED' and 'DEGRADED' that may apply to a particular exchange should be listed in the ICD. If the value is 'DEGRADED', information on the nature of the degradation may be conveyed via the COMMENT mechanism. The default value shall be 'VALIDATED'.</p>	<p>RAW VALIDATED DEGRADED</p>	No
CORRECTION_RANGE CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 CORRECTION_DOPPLER CORRECTION_TROPO_DRY CORRECTION_TROPO_WET CORRECTION_CP *	<p>The set of CORRECTION_ keywords may be used to reflect the values of corrections that have been applied to the data (e.g., ranging station delay calibration, etc.). This information may be provided to the user, so that the base measurement could be recreated if a different correction procedure is desired. Tracking data should be corrected for ground delays only. Note that it may not be feasible to apply all ground corrections for a near real time transfer. Units for the correction shall be the same as those for the applicable observable.</p> <p>* The CORRECTION_CP keyword applies to ionospheric correction only, not solar plasma or other plasmas.</p>	1.35	No
META_STOP	<p>The META_STOP keyword shall delineate the end of the TDM Metadata block within the message. It must appear on a line by itself.</p>	N/A	Yes

3.3.2 MODE AND PATH SETTINGS FOR TYPICAL TRACKING SESSIONS

The following sections discuss possible relationships between the 'MODE', 'PATH', and 'PARTICIPANT_n' keywords. This section is provided in order to facilitate coding of TDMs that correspond to typical tracking sessions (e.g., one-way, two-way, three-way, etc.).

3.3.3 ONE-WAY DATA

3.3.3.1 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.3.2 For one-way data, the signal path generally originates at the spacecraft transmitter, so the spacecraft's participant number shall be the first number in the value assigned to the PATH keyword. The receiver, which may be a tracking station or another spacecraft, shall be represented by the second number in the value of the PATH keyword.

EXAMPLES – 'PATH=1,2' indicates transmission from PARTICIPANT_1 to PARTICIPANT_2; 'PATH=2,1' indicates transmission from PARTICIPANT_2 to PARTICIPANT_1.

NOTE – See figures D-1 and D-2 for example TDMs containing one-way tracking data.

3.3.4 TWO-WAY DATA

3.3.4.1 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.4.2 For two-way data, the signal path originates at a ground antenna (or a 'first spacecraft'), so the uplink (or crosslink) transmit participant number shall be the first number in the value assigned to the PATH keyword. The participant number of the transponder onboard the spacecraft to which the signal is being uplinked shall be the second number in the value assigned to the PATH keyword. The third entry in the PATH keyword value shall be the same as the first (two way downlink is received at the same participant which does the uplink). Both PARTICIPANT_1 and PARTICIPANT_2 may be spacecraft as in the case of a spacecraft-spacecraft exchange.

EXAMPLES – 'PATH=1,2,1' indicates transmission from PARTICIPANT_1 to PARTICIPANT_2, with final reception at PARTICIPANT_1; 'PATH=2,1,2' indicates transmission from PARTICIPANT_2 to PARTICIPANT_1, with final reception at PARTICIPANT_2.

NOTE – See figures D-3 and D-4 for example TDMs containing two-way tracking data.

3.3.5 THREE-WAY DATA

3.3.5.1 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.5.2 For three-way data, the signal path originates with a ground station (uplink antenna), so the participant number of the uplink station shall be the first entry in the value assigned to the PATH keyword. The participant number of the transponder onboard the spacecraft to which the signal is being uplinked shall be the second number in the value assigned to the PATH keyword. The participant number of the downlink antenna shall be the third number in the value assigned to the PATH keyword.

3.3.5.3 For three-way data, the first and last numbers in the value assigned to the PATH keyword must be different.

EXAMPLES – 'PATH=1,2,3' indicates transmission from PARTICIPANT_1 to PARTICIPANT_2, with final reception at PARTICIPANT_3.

NOTE – See figure D-5 for an example TDM containing three-way tracking data.

3.3.6 N-WAY DATA

3.3.6.1 One-way, two-way and three-way tracking cover the bulk of tracking sequences. However, four-way and greater (*n*-way) scenarios are possible (e.g., via use of one or more relay satellites). These may be accomplished via the sequence assigned to the PATH keyword.

3.3.6.2 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.6.3 The value assigned to the PATH keyword shall convey the signal path among the participants followed by the signal, e.g., 'PATH=1,2,3,2,1' or 'PATH=1,2,3,4' represent two different four-way tracking signal paths.

3.3.6.4 In this version of the TDM, the maximum number of participants per segment shall be five. If more than five participants are defined (i.e., PARTICIPANT_6 +), then special arrangements shall be made; these should be specified in the ICD.

NOTE – See figure D-6 for an example TDM containing four-way tracking data.

3.3.7 DIFFERENCED MODES AND VLBI DATA

3.3.7.1 For differenced data and VLBI data, there are two different values of the MODE keyword that apply: 'SINGLE-DIFF' and 'DOUBLE-DIFF'. Differenced data can include differenced Doppler and differenced range (see references [E8] and [E10]).

3.3.7.2 When the MODE is ‘SINGLE-DIFF’, at least three participants shall be present. PARTICIPANT_1 must be the transmitting participant (source of the signal). PARTICIPANT_2 and PARTICIPANT_3 are the receiving participants.

3.3.7.3 When the mode is ‘SINGLE-DIFF’, the observable is calculated by subtracting the value achieved for the measurement between PARTICIPANT_2 and PARTICIPANT_1 from the measurement between PARTICIPANT_3 and PARTICIPANT_1 (i.e., ‘ $p_3p_1 - p_2p_1$ ’, where ‘ p_n ’ represents ‘PARTICIPANT_ n ’ and p_ip_j represents a measurement between p_i and p_j). Only the final observable shall be communicated via the TDM.

3.3.7.4 The ‘DOUBLE-DIFF’ value of MODE applies in cases where two signal sources are measured simultaneously (e.g., same beam interferometry or a delta-DOR [delta differenced one-way range] measurement session where the quasar and spacecraft downlinks are measured simultaneously). This observation pattern is performed simultaneously using two receivers in different antenna complexes, achieving the long baseline desired. The signals recorded at the two complexes are correlated, and pointing angle values are differenced to derive the observable.

3.3.7.5 When the MODE is ‘DOUBLE-DIFF’, at least four participants shall be present. PARTICIPANT_1 and PARTICIPANT_2 must be the transmitting participants (source of the signals). PARTICIPANT_3 and PARTICIPANT_4 are the receiving participants.

3.3.7.6 When the MODE is ‘DOUBLE-DIFF’, the observable is calculated ($p_4p_2 - p_3p_2$) - ($p_4p_1 - p_3p_1$), where ‘ p_n ’ represents ‘PARTICIPANT_ n ’ and p_ip_j represents a measurement between p_i and p_j . Only the final observable shall be communicated via the TDM.

NOTE – In many measurement sessions that are called ‘delta-DOR’, the measurement data is collected via a process in which the antenna slews from a spacecraft downlink to a quasar and back to the spacecraft during the tracking pass. This sequence may occur multiple times. This observation pattern is performed ‘simultaneously’ using two receivers in different antenna complexes, achieving the long baseline desired. However, because the measurements are not truly simultaneous, the output data are actually data that can be single-differenced and then extrapolated to achieve a simulated simultaneous measurement. The collection of data that contains some actual measurement data and some extrapolated data is then differenced to create a pseudo double-differenced data product.

3.3.7.7 For differenced data types, there is a metadata keyword ‘DIFF_MODE’ that determines how the observable should be interpreted. If the differenced or VLBI observable is a value with units of ‘seconds’, then the ‘DIFF_MODE’ of DELAY applies. This value of ‘DIFF_MODE’ indicates that the observable represents the difference in arrival time for a given wavefront at the two stations involved in the measurement. If the differenced or VLBI observable is a distance, then the ‘DIFF_MODE’ of RANGE applies. This value of ‘DIFF_MODE’ indicates that the observable represents the difference in distance to the spacecraft at a given reception time.

3.3.7.8 If differenced Doppler is provided, the ‘RECEIVE_FREQ’ keyword shall be used. If differenced range is provided, the ‘RANGE_OBS’ keyword shall be used.

3.3.7.9 If the TDM contains two-way or three-way differenced Doppler data, then a history of the uplink frequencies shall be provided with the RECEIVE_FREQ_n keyword in order to process the data correctly.

NOTE – See figures D-8, D-9, and D-10 for example TDMs containing single differenced tracking data. See figure D-11 for an example TDM containing double differenced tracking data.

3.3.8 ANGLE DATA

Angle data is applicable for any tracking scenario where MODE=SEQUENTIAL is specified, but is based on pointing with respect to the two final participants only (e.g., spacecraft downlink to an antenna, pointing of a CCD camera, etc.).

NOTE – See figure D-12 for an example TDM containing angle data.

3.3.9 MEDIA, WEATHER, ANCILLARY DATA, & UPLINK ONLY

When all the data in a TDM segment is media related, weather related, ancillary-data related, or uplink data only, then the value of the MODE keyword shall be ‘N/A’ and the PATH keyword shall not be used. Data of this type may be relative to a reference location within the tracking complex; in this case the methods used to extrapolate the measurements to other antennas should be specified in the ICD. In the case where a reference location is used, there shall be only one participant (PARTICIPANT_1), and it is the reference antenna. An exception to the single participant segment would be where ionospheric charged particle delays are provided for a line-of-sight between the antenna and a specific spacecraft.

NOTE – See figures D-13 through D-16 for example TDMs containing tracking data of these types.

3.4 TDM DATA BLOCK (GENERAL SPECIFICATION)

3.4.1 The data portion of the TDM segment shall consist of one or more Tracking Data Records. Each Tracking Data Record shall have the following generic format:

keyword = timetag measurement

More detail on the generic format of a Tracking Data Record is shown in table 3-4.

Table 3-4: Tracking Data Record Generic Format

Element		Description	Examples	Obligatory
<keyword>		Data type keyword from the list specified in 3.5. Note that some keywords constitute a hierarchy, and are constructed from a <prefix><suffix> construction pair (in preparation for the XML implementation).	See 3.5	Yes
=		Equals sign	=	Yes
value	<timetag>	Time associated with the tracking observable. Timetags may be in a non-chronological sequence. Tracking data shall be tagged in the applicable TIME_SYSTEM. Format shall be the same as for START_TIME and STOP_TIME metadata keywords. Interpretation of the timetag is as follows: Uplink data: transmit time. Downlink data: determined by values of TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords, as applicable. Other data (e.g., meteorological, media, clock bias/drift): the time the measurement was taken.	2003-205T18:00:01.275	Yes
	<measurement>	Tracking observable (measurement or calculation) in units defined in the TDM.	See 3.5.	Yes

3.4.2 Each Tracking Data Record must be provided on a single line.

3.4.3 Each Tracking Data Record shall contain a value that depends upon the data type keyword used. The value shall consist of two components: a timetag and a tracking observable (a measurement or calculation based on measurements); either without the other is useless for tracking purposes. Hereafter, the term ‘measurement’ shall be understood to include calculations based on measurements as noted above.

3.4.4 Applicable keywords and their associated characteristics are detailed in 3.5.

3.4.5 In any particular block of Tracking Data Records, all keywords shall be optional because they depend upon the characteristics of the data collection activity; however, the keyword associated with at least one tracking data type must be present.

3.4.6 At least one blank character must be used to separate the timetag and the observable in the value associated with each Tracking Data Record.

3.4.7 The data portion of the TDM segment shall be delineated by the 'DATA_START' and 'DATA_STOP' keywords. These keywords are intended to facilitate file parsing, and will also serve to advise the recipient that all the data associated with the immediately preceding TDM Metadata block have been received (the rationale for including this is that data volumes can be very large, so knowing when the data ends is desirable). The TDM recipient may process the 'DATA_STOP' keyword as a 'local' end-of-file marker.

3.4.8 No required ordering of Tracking Data Records shall be imposed, because there are certain scenarios in which data are collected from multiple sources that are not processed in strictly chronological order; thus it is only possible to generate data in chronological order if it is sorted post-pass. Also, some TDM creators may wish to sort tracking data by keyword rather than by timetag. However, each keyword/timetag combination must be unique within a given block of Tracking Data Records (i.e., a given keyword/timetag combination shall not be repeated in the same block of Tracking Data Records). The time duration between timetags may be constant, or may vary, within any given TDM.

3.4.9 Every tracking instrument shall have a defined reference location that could be defined in the Orbit Data Messages (ODM) format (reference [4]), possibly extended to define spacecraft body-fixed axes. This reference location shall not depend on the observing geometry. The tracking instrument locations should be conveyed via an ICD.

3.4.10 The measurement shall be converted to an equipment-independent quantity, e.g. frequencies shall be reported at the 'sky level' (i.e., actual transmitted/received frequencies, unless the `FREQ_OFFSET` keyword is used in the metadata).

3.4.11 The tracking data measurements shall be corrected with the best estimate of all known instrument calibrations, such as path delay calibrations between the reference point and the tracking equipment, if applicable. Tracking data should be corrected for ground delays only. The corrections that have been applied should be specified to the message recipient via use of the 'CORRECTION_' keywords in the metadata.

3.4.12 Other corrections applied to the data, such as media corrections, shall be agreed by the service provider and the customer Agencies and specified in an ICD.

NOTE – These measures should reduce the requirement for consumers of tracking data to have detailed knowledge of the underlying structure of the hardware/software system that performed the measurements.

3.4.12.1 The party that will perform any applicable spin corrections should be specified in the ICD (most appropriate party may be the party that operates the spacecraft).

3.4.12.2 In general, tropospheric corrections shall not be applied; tropospheric corrections shall be applied by the TDM recipient. (Note that a 'CORRECTION_TROPO' keyword is provided, in the event that the TDM recipient desires to receive data that has already been corrected).

3.4.13 The TDM Tracking Data Record keyword assignments are shown in 3.5, which specifies for each keyword:

- the keyword to be used;
- the data type to which it applies;
- applicable units for the associated values;
- the range of values, where applicable;
- default values, where applicable;
- applicable comments.

NOTE – See annex D for detailed usage examples.

3.4.14 All data type keywords in the TDM Data Block must be from 3.5. The standard tracking data types are extended to cover also some of the ancillary data that may be required for precise trajectory determination work. Subsection 3.5 identifies the most frequently used data and ancillary types.

3.5 TDM DATA BLOCK KEYWORDS

3.5.1 OVERVIEW

This subsection describes each of the keywords that may be used in the data portion of the TDM segment. In general, there is no required order in the data portion of the TDM segment. Exceptions are the 'DATA_START' and 'DATA_STOP' keywords, which must be the first and last keywords in the Data Block, respectively. For ease of reference, table 3-5 containing all the keywords sorted in alphabetical order is shown immediately below; descriptive information about the keywords is shown starting in 3.5.2. The remainder of this subsection is organized according to the class of data to which the keyword applies (e.g., all the angle related keywords are together).

Table 3-5: Summary Table of TDM Data Block Keywords (Alpha Order)

Keyword	Units	Text Link
AGC	dBm	3.5.2.1
ANGLE_1	deg	3.5.3.2
ANGLE_2	deg	3.5.3.3
AZIMUTH_RATE	deg/s	3.5.2.2
CARRIER_SNR	dB-Hz	3.5.2.3
CLOCK_BIAS	s	3.5.4.1
CLOCK_DRIFT	s/s	3.5.4.2
COMMENT	n/a	3.5.7.1
CPDELAY	TECU	3.5.5.1
DATA_START	n/a	3.5.7.2
DATA_STOP	n/a	3.5.7.3
PRESSURE	hPa (hectopascal)	3.5.6.1
RANGE_OBS	per RANGE_UNITS keyword in metadata	3.5.2.4
RANGE_RATE	per RANGE_UNITS keyword in metadata	3.5.2.4
RANGE_SNR	dB-Hz	3.5.2.4
RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.5
RECEIVE_FREQ	Hz	3.5.2.5
RHUMIDITY	%	3.5.6.2
TEMPERATURE	K	3.5.6.3
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.6
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.6
TROPO_DRY	m	3.5.5.2
TROPO_WET	m	3.5.5.2

NOTE – Table 3-6 repeats the information from table 3-5 in Category Order.

Table 3-6: Summary Table of TDM Data Block Keywords (Category Order)

Keyword	Units	Text Link
Signal Related Keywords		3.5.2
AGC	dBm	3.5.2.1
AZIMUTH_RATE	deg/s	3.5.2.2
CARRIER_SNR	dB-Hz	3.5.2.3
RANGE_OBS	per RANGE_UNITS keyword in metadata	3.5.2.4
RANGE_RATE	per RANGE_UNITS keyword in metadata	3.5.2.4
RANGE_SNR	dB-Hz	3.5.2.4
RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.5
RECEIVE_FREQ	Hz	3.5.2.5
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.6
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.6
Angle Related Keywords		3.5.3
ANGLE_1	deg	3.5.3.2
ANGLE_2	deg	3.5.3.3
Time Related Keywords		3.5.4
CLOCK_BIAS	s	3.5.4.1
CLOCK_DRIFT	s/s	3.5.4.2
Media Related Keywords		3.5.5
CPDELAY	TECU	3.5.5.1
TROPO_DRY	m	3.5.5.2
TROPO_WET	m	3.5.5.2
Meteorological Related Keywords		3.5.6
PRESSURE	hPa (hectopascal)	3.5.6.1
RHUMIDITY	%	3.5.6.2
TEMPERATURE	K	3.5.6.3
Miscellaneous Keywords		3.5.7
COMMENT	n/a	3.5.7.1
DATA_START	n/a	3.5.7.2
DATA_STOP	n/a	3.5.7.3

3.5.2 SIGNAL RELATED KEYWORDS

3.5.2.1 AGC

The AGC keyword conveys the strength of the radio signal transmitted by the spacecraft as received at the ground station. The Automatic Gain Control (AGC) level reports how much it was necessary to amplify the incoming signal before passing it on to downstream components. This is an indirect way of reporting the strength of the signal received from the spacecraft, in decibels (referenced to 1 milliwatt). The unit for the AGC keyword is dBm. The value shall be a double precision value, and may be positive, zero, or negative.

3.5.2.2 AZIMUTH_RATE

The AZIMUTH_RATE keyword shall represent an interferometer azimuth rate, for example, in a Connected Element Interferometry session. The units for AZIMUTH_RATE shall be deg/s. The value shall be a double precision value.

3.5.2.3 CARRIER_SNR

The value associated with the CARRIER_SNR keyword shall be the carrier power to noise spectral density ratio (P_c/N_o). The units for CARRIER_SNR shall be dB-Hz. The value shall be a double precision value.

3.5.2.4 RANGE

3.5.2.4.1 The RANGE keyword prefix shall be used to indicate that the values represent measurements from ambiguous ranging systems, differenced range, skin radar, proximity radar, or similar radar. There shall be three suffixes associated with the RANGE prefix, i.e., _OBS, _RATE, and _SNR. Thus the three keywords are RANGE_OBS, RANGE_RATE, and RANGE_SNR.

NOTE – The TDM specifically excludes Satellite Laser Ranging (SLR), which is already transferred via an internationally standardized format documented at <http://ilrs.gsfc.nasa.gov/>.

3.5.2.4.2 RANGE_OBS: The value associated with the RANGE_OBS keyword is the range observable. The units for RANGE_OBS shall be as specified by the 'RANGE_UNITS' metadata keyword (either 'RU' for 'range units', 'S' for 'seconds', or 'KM' for 'kilometers'). If range units are used, the definition of the range unit should be specified in the ICD. The value shall be a double precision value, and is generally positive (exceptions to this could occur if the data is a differenced type).

3.5.2.4.3 RANGE_RATE: The value associated with the RANGE_RATE keyword is the rate of change in the RANGE_OBS starting at the timetag and continuing until the next timetag. The units for RANGE_RATE shall be congruent with the decision on units for

RANGE_OBS, i.e., if the units specified in the metadata are 'RU', then the units for RANGE_RATE are 'RU/S'; if the units specified in the metadata are 'S', then the units for RANGE_RATE are 'S/S'; and if the units specified in the metadata are 'KM', then the units for RANGE_RATE are 'KM/S'.

3.5.2.4.4 RANGE_SNR: The value associated with the RANGE_SNR keyword shall be the ranging power to noise spectral density ratio (Pr/No). The units for RANGE_SNR shall be dB-Hz. It shall be a double precision value, and may be positive, zero, or negative.

3.5.2.5 RECEIVE_FREQ

3.5.2.5.1 The RECEIVE_FREQ keyword shall be used to indicate that the values represent measurements of the received frequency. The keyword is indexed to accommodate a scenario in which multiple downlinks are used; it may also be used without an index where the frequency cannot be associated with a particular participant (e.g., in the case of a differenced Doppler measurement). The value associated with the RECEIVE_FREQ keyword shall be the average frequency observable over the INTEGRATION_INTERVAL specified in the metadata, at the measurement timetag. The interpretation of the timetag shall be determined by the combined keyword settings of the TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords. The units for RECEIVE_FREQ shall be Hertz (Hz). The value shall be a double precision value (generally positive, but could be negative or zero if used with the 'FREQ_OFFSET' metadata keyword). Note that the downlink band is not specified in the TDM; rather, it is inferred from the received frequency.

3.5.2.5.2 Using the RECEIVE_FREQ, the instantaneous Doppler measurement is calculated as follows:

$$\text{Doppler_shift} = - ((\text{transmit_freq} * \text{transponder_ratio}) - \text{receive_freq})$$

or

$D_m = -((F_t * tr) - F_r)$, where 'D_m' is the Doppler measurement, 'F_t' is the transmitted frequency, 'tr' is the transponder ratio (tr=1 for one-way), and 'F_r' is the RECEIVE_FREQ.

For integrated Doppler, the Doppler measurement is calculated as follows, where Δt is the value assigned to the INTEGRATION_INTERVAL keyword:

$$D_m = \frac{-1}{\Delta t} \int_{t + (\frac{-1}{2} + \alpha)\Delta t}^{t + (\frac{1}{2} + \alpha)\Delta t} ((F_t * tr) - F_r) dt$$

The limits of integration are determined by the INTEGRATION_REF keyword in the metadata; the constant α in the equation has the value $-1/2$, 0, or $1/2$ for the INTEGRATION_REF values of 'END', 'MIDDLE', or 'START', respectively (see reference [E10]).

INTEGRATION_REF	END	MIDDLE	START
α	$\alpha = -1/2$	$\alpha = 0$	$\alpha = 1/2$
Upper Limit	t	$t + 1/2\Delta t$	$t + \Delta t$
Lower Limit	$t - \Delta t$	$t - 1/2\Delta t$	t

3.5.2.5.3 The transponder ratios used for interagency exchanges should be specified in the ICD.

3.5.2.5.4 The equation for four-way Doppler should be in the ICD since the four-way connections tend to be implementation dependent.

3.5.2.6 TRANSMIT

3.5.2.6.1 The TRANSMIT keyword prefix shall be used to indicate that the values represent measurements of the transmitted frequency from uplink operations. The TRANSMIT keywords are indexed to accommodate scenarios in which multiple uplinks are used. There shall be two suffixes associated with the TRANSMIT prefix, i.e., `_FREQ` and `_FREQ_RATE`. Thus the two keywords are `TRANSMIT_FREQ` and `TRANSMIT_FREQ_RATE`.

3.5.2.6.2 `TRANSMIT_FREQ`: The value associated with the `TRANSMIT_FREQ` keyword shall be the starting frequency observable at the timetag. The units for `TRANSMIT_FREQ` shall be Hertz (Hz). The value shall be a positive double precision value. Note that the uplink band is not specified in the TDM; rather, it is inferred from the transmitted frequency. The turnaround ratios necessary to calculate the predicted downlink frequency should be specified in the ICD.

3.5.2.6.3 `TRANSMIT_FREQ_RATE`: The value associated with the `TRANSMIT_FREQ_RATE` keyword is the rate of change of the frequency starting at the timetag and continuing until the next timetag. The units for `TRANSMIT_FREQ_RATE` shall be Hertz-per-second (Hz/s). The value shall be a double precision value, and may be negative, zero, or positive. If the `TRANSMIT_FREQ_RATE` is not specified, it is assumed to be zero (i.e., constant frequency).

3.5.2.6.4 Usage notes: when the data mode is one-way (i.e., `MODE=SEQUENTIAL`, `PATH=1,2` or `PATH=2,1`), the signal is at the beacon frequency transmitted from the spacecraft. If a given spacecraft has more than one transponder, then there should be unique names specified in the ICD for each transponder (e.g., `Cassini_S`, `Cassini_X`, `Cassini_Ka`). If a TDM is constructed with only transmit frequencies, then the `MODE` is 'N/A' and the `PATH` keyword defines the signal path.

3.5.3 ANGLE DATA KEYWORDS

3.5.3.1 General

Angle data is measured at the ground antenna, using downlink data only, regardless of the mode of the tracking session. There shall be two angle keywords: ANGLE_1, and ANGLE_2. The ANGLE_TYPE metadata keyword indicates how these two keywords should be interpreted.

3.5.3.2 ANGLE_1

The value assigned to the ANGLE_1 keyword represents the azimuth, right ascension, or 'X' angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The angle measurement shall be a double precision value as follows: $-180.0 \leq \text{angle_1} < 360.0$. Units shall be degrees.

3.5.3.3 ANGLE_2

The value assigned to the ANGLE_2 keyword represents the elevation, declination, or 'Y' angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The angle measurement shall be a double precision value as follows: $-180.0 \leq \text{angle_2} < 360.0$. Units shall be degrees.

3.5.4 TIME RELATED KEYWORDS

3.5.4.1 CLOCK_BIAS

In general, the timetags provided for the tracking data should be corrected, but when that is not possible (e.g. for three-way data or differenced data types), then this data type may be used. The CLOCK_BIAS keyword can be used by the message recipient to adjust timetag measurements by a specified amount with respect to a common reference, normally UTC. The clock bias is stated in the data, but the timetags in the message have not been corrected by applying the bias. Normally the time related data such as CLOCK_BIAS data and CLOCK_DRIFT data should appear in a dedicated TDM segment, i.e., not mixed with signal data or other data types. A single participant (PARTICIPANT_1) is acceptable for use with CLOCK_BIAS data. The units for CLOCK_BIAS shall be shown in seconds of clock bias. The value shall be a double precision value, and may be positive or negative. The default value shall be 0.0.

3.5.4.2 CLOCK_DRIFT

In general ground-based clocks in tracking stations are sufficiently stable that a measurement of the clock drift may not be necessary. However, for spacecraft-to-spacecraft exchanges, there may be onboard clock drifts that are sufficiently significant that they should be accounted for in

the measurements and calculations. Drift in clocks may also be an important factor where differenced data is being exchanged. The `CLOCK_DRIFT` keyword should be used to adjust timetag measurements by an amount that is a function of time with respect to a common reference, normally UTC (as opposed to the `CLOCK_BIAS`, which is meant to be a constant adjustment). Thus `CLOCK_DRIFT` could be used to calculate an interpolated `CLOCK_BIAS` between two timetags, by multiplying the `CLOCK_DRIFT` measurement at the timetag by the number of seconds desired and adding it to the `CLOCK_BIAS`. Normally the time related data such as `CLOCK_DRIFT` data and `CLOCK_BIAS` data should appear in a dedicated TDM segment, i.e., not mixed with signal data or other data types. A single participant (`PARTICIPANT_1`) is acceptable for use with `CLOCK_DRIFT` data. The units for `CLOCK_DRIFT` shall be shown in seconds-per-second (s/s) of clock drift. The value shall be a double precision value, and may be positive or negative. The default value shall be 0.0.

3.5.5 MEDIA RELATED KEYWORDS

3.5.5.1 CPDELAY

The `CPDELAY` keyword shall be used to convey the line of sight, one way charged particle delay or total electron count (TEC) at the timetag associated with a tracking measurement, which is calculated by integrating the electron density along the propagation path (electrons/m²). The charged particles could have several sources, e.g., solar plasma, Earth ionosphere, or the Io plasma torus. The units for the `CPDELAY` keyword are Total Electron Count Units (TECU), where 1 TECU = 10¹⁶ electrons/m². The value shall be a positive double precision value (the TEC along the satellite line of sight may vary between 1 and 400 TECU; larger values may be observed during periods of high solar activity). This keyword should appear in its own tracking data segment with `PARTICIPANTS` being one spacecraft and one antenna, and a `MODE` setting of 'N/A'.

3.5.5.2 TROPO

3.5.5.2.1 The `TROPO` keyword prefix shall be used to indicate that the values represent measurements associated with the dry and wet zenith delay through the troposphere at the timetag. There shall be two suffixes associated with the `TROPO` prefix, i.e., `_DRY` and `_WET`. Thus the two keywords are `TROPO_DRY` and `TROPO_WET`. There should be an agreed upon elevation mapping specified in the ICD (e.g., the Niell mapping function developed for VLBI applications). Tropospheric corrections should be done by the recipient of the TDM; the required correction is the value associated with this keyword at the timetag. Recommended polynomial interpolations (if applicable) should be specified in the ICD.

3.5.5.2.2 `TROPO_DRY`: The value associated with the `TROPO_DRY` keyword shall be the dry zenith delay measured at the timetag. The units for `TROPO_DRY` shall be meters (m). The value shall be a double precision value (0.0 ≤ `TROPO_DRY`).

3.5.5.2.3 TROPO_WET: The value associated with the TROPO_WET keyword shall be the wet zenith delay measured at the timetag. The units for TROPO_WET shall be meters (m). The value shall be a double precision value ($0.0 \leq \text{TROPO_WET}$).

3.5.6 METEOROLOGICAL RELATED KEYWORDS

3.5.6.1 PRESSURE

The value associated with the PRESSURE keyword shall be the atmospheric pressure observable, specified in hectopascal (1 hectopascal = 1 millibar). The PRESSURE shall be a double precision value; practically speaking it is always positive.

3.5.6.2 RHUMIDITY

The value associated with the RHUMIDITY keyword shall be the relative humidity observable, specified in percent. RHUMIDITY shall be a double precision type value, $0 \leq \text{RHUMIDITY} \leq 100$.

3.5.6.3 TEMPERATURE

The value associated with the TEMPERATURE keyword shall be the temperature observable, specified in Kelvin (K). The TEMPERATURE shall be a positive double precision type value.

3.5.7 MISCELLANEOUS KEYWORDS

3.5.7.1 COMMENT

The COMMENT keyword is not required. See 4.5 for full details on usage of the COMMENT keyword.

3.5.7.2 DATA_START

The 'DATA_START' keyword must be the first keyword in the data portion of the TDM segment. The keyword shall appear on a line by itself with no timetags or values, which serves to delimit the Tracking Data Records section. Example: 'DATA_START'.

3.5.7.3 DATA_STOP

The 'DATA_STOP' keyword must be the last keyword in the data portion of the TDM segment. The keyword shall appear on a line by itself with no timetags or values, which serves to delimit the Tracking Data Records section. Example: 'DATA_STOP'.

4 TRACKING DATA MESSAGE SYNTAX

4.1 GENERAL

The TDM shall observe the syntax described in 4.2 through 4.5.

4.2 TDM LINES

4.2.1 The TDM file shall consist of a set of TDM lines. The TDM line must contain only printable ASCII characters and blanks. ASCII control characters (such as TAB, etc.) must not be used, except as indicated below for the termination of the TDM line. A TDM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

4.2.2 Each TDM line shall be one of the following:

- Header line;
- Metadata block line;
- Tracking Data Record line;
- Comment line;
- blank line.

4.2.3 All Header, Metadata block, and Tracking Data Record lines, with exceptions as noted below, shall use ‘keyword = value’ syntax, abbreviated as KVN. The following distinctions in KVN syntax shall apply for TDM lines:

- TDM lines in the Header and Metadata block shall consist of a keyword, followed by an equals sign ‘=’, followed by a single value assignment.
- TDM lines in the Data block shall consist of a keyword, followed by an equals sign ‘=’, followed by a value that consists of two elements (essentially an ordered pair): a timetag and the measurement or calculation associated with that timetag (either without the other is unusable for tracking purposes). The timetag and measurement/calculation in the Tracking Data Record line must be separated by at least one blank character (white space).
- The keywords META_START, META_STOP, DATA_START, and DATA_STOP are exceptions to the KVN syntax.

4.2.4 Keywords must be uppercase and must not contain blanks.

4.2.5 Any white space immediately preceding or following the keyword shall not be significant.

4.2.6 Any white space immediately preceding or following the equals sign '=' shall not be significant.

4.2.7 Any white space immediately preceding the end of line shall not be significant.

4.2.8 Blank lines may be used at any position within the TDM.

4.2.9 TDM lines shall be terminated by a single Carriage Return or a single Line Feed or a Carriage Return/Line Feed pair or a Line Feed/Carriage Return pair.

4.3 TDM VALUES

4.3.1 A non-null value field must be specified for each obligatory keyword provided. If an actual observable value is not available, then 'N/A' must be the value specified for an obligatory keyword.

4.3.2 Integer values shall consist of a sequence of decimal digits with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading zeros may be used. The range of values that may be expressed as an integer is:

$$-2\,147\,483\,648 \leq x \leq +2\,147\,483\,647 \text{ (i.e., } -2^{31} \leq x \leq 2^{31}-1).$$

4.3.3 Non-integer numeric values may be expressed in either fixed- or floating-point notation. Both representations may be used within a TDM.

4.3.4 Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading and trailing zeros may be used. If the fractional part is zero, the decimal point and following zero(s) may be omitted. There must be a leading zero if $-1.0 < x < 1.0$. The number of digits shall be 18 or fewer.

4.3.5 Non-integer numeric values expressed in floating-point notation shall consist of a sign, a mantissa, an alphabetic character indicating the division between the mantissa and exponent, and an exponent, constructed according to the following rules:

- The sign may be '+' or '-'. If the sign is omitted, '+' shall be assumed.
- The mantissa must be a string of no more than 16 decimal digits with a decimal point '.' in the second position of the ASCII string, separating the integer portion of the mantissa from the fractional part of the mantissa.
- The character used to denote exponentiation shall be 'E' or 'e'. If the character indicating the exponent and the following exponent are omitted, an exponent value of zero shall be assumed (essentially yielding a fixed-point value).

- The exponent must be an integer, and may have either a ‘+’ or ‘-’ sign (if the sign is omitted, then ‘+’ is assumed).
- The maximum positive floating-point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating-point value is approximately 4.94E-324, with 16 significant decimal digits precision.

NOTE – These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer ‘xsd:int’, ‘decimal’ and ‘double’ respectively. The specifications for floating-point values conform to the IEEE double precision type. Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies because of their implementation specific attributes.

4.3.6 Text value fields may be constructed using mixed case; case shall not be significant.

4.3.7 Blanks shall be prohibited within numeric values and time values.

4.3.8 In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks between values shall be retained (shall be significant) but multiple blanks shall be equivalent to a single blank.

4.4 UNITS IN THE TDM TRACKING DATA RECORD

4.4.1 For documentation purposes and clarity, units may be included as ASCII text after a value. If units are displayed, they must match the units specified in table 3-5. If units are displayed, then:

- a) there must be at least one blank character between the value and the units text;
- b) the units must be enclosed within square brackets (e.g. ‘[km]’);
- c) exponents of units shall be denoted with a double asterisk (i.e. ‘**’, for example, $m/s^2 = m/s^{**2}$); and
- d) The units documentation may be constructed using all uppercase or all lowercase characters.

4.4.2 Since the units are fixed in the TDM, and the units are provided only as documentation, the units shall not be used to make processing decisions, i.e., they shall be treated as comments.

4.5 COMMENTS IN A TDM

4.5.1 Comments may be used to provide any pertinent information associated with the data that is not covered via one of the keywords. This additional information is intended to aid in

consistency checks and elaboration where needed. Comments shall not be required for successful processing of a file; i.e., comment lines shall be optional.

4.5.2 Comment lines may occur

- at any position after the first non-blank line in the TDM Header;
- at the beginning of the TDM Metadata block (i.e., between the META_START keyword and the TIME_SYSTEM keyword);
- at the beginning of the TDM Data block (i.e., between the 'DATA_START' keyword and the first Tracking Data Record).

4.5.3 Comments must not appear between Tracking Data Records.

4.5.4 All comment lines shall begin with the 'COMMENT' keyword followed by a single space (note: may also be preceded by spaces). The 'COMMENT' keyword must appear on every comment line, not just the first comment line. After the keyword, the remainder of the line shall be the comment value. White space shall be retained (is significant) in comment values.

4.5.5 Conventions for particular comments in the TDM that may be required between any two participating agencies should be specified in the ICD.

4.5.6 Descriptions of any ancillary data that cannot be accommodated via keywords in the TDM may have to be specified via comments, and should be outlined in the ICD.

4.5.7 Given that TDM files may be very large, and generally produced via automation, using the COMMENT feature of the TDM may have limited utility. On the other hand, a simple utility could be developed to search for and extract all the comments in a TDM to make them easily reviewable. Existing 'freeware' utilities (e.g., UNIX 'grep') could also be used for this purpose.

ANNEX A

RATIONALE FOR TRACKING DATA MESSAGES

(INFORMATIVE)

A1 GENERAL

This annex presents the rationale behind the design of the Tracking Data Message. It may help the application engineer construct a suitable message. Corrections and/or additions to these requirements may occur during future updates.

A specification of requirements agreed to by all parties is essential to focus design and to ensure the product meets the needs of the Member Agencies. There are many ways of organizing requirements, but the categorization of requirements is not as important as the agreement to a sufficiently comprehensive set. In this section, the requirements are organized into three categories:

Primary Requirements - These are the most elementary and necessary requirements. They would exist no matter the context in which the CCSDS is operating, i.e., regardless of pre-existing conditions within the CCSDS or its Member Agencies.

Heritage Requirements - These are additional requirements that derive from pre-existing Member Agency requirements, conditions or needs. Ultimately these carry the same weight as the Primary Requirements. This draft Recommended Standard reflects heritage requirements pertaining to some of the technical participants' home institutions collected during the preparation of the draft Recommended Standard; it does not speculate on heritage requirements that could arise from other Member Agencies.

Desirable Characteristics - These are not requirements, but they are felt to be important or useful features of the draft Recommended Standard.

A2 PRIMARY REQUIREMENTS ACCEPTED FOR TRACKING DATA MESSAGES

Table A-1: Primary Requirements

<u>ID</u>	<u>Requirement</u>	<u>Trace</u>
A-1-1	Data must be provided in digital form (computer file).	2.2
A-1-2	The object being tracked must be clearly identified and unambiguous. ¹	3.3
A-1-3	All primary resources used in the tracking session must be clearly identified and unambiguous.	3.3
A-1-4	Time measurements (time stamps, timetags, or epochs) must be provided in a commonly used, clearly specified system.	3.3
A-1-5	The time bounds of the tracking data must be unambiguously specified.	3.3, 3.4
A-1-6	The standard must provide for clear specification of units of measure.	4.4
A-1-7	Files must be readily portable between and useable within ‘all’ computational environments in use for the processing of tracking data by Member Agencies.	3
A-1-8	Files must have means of being uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	3.1.3
A-1-9	File name syntax and length must not violate computer constraints for those computing environments in use for the processing of tracking data by Member Agencies.	2.2
A-1-10	The Tracking Data Message format shall be independent of the equipment that was used to perform the tracking.	3, 4.2
A-1-11	Every tracking instrument shall have a defined reference location that could be defined in the ODM format, possibly extended to define spacecraft body-fixed axis. This reference location should not depend on the observing geometry.	3.4
A-1-12	The timetag of the tracking data shall always be unambiguously specified with respect to the measurement point or instrument reference point.	3.4
A-1-13	The observable shall be corrected with the best estimate of all known tracking instrument calibrations, such as path delay calibrations between the reference point and the tracking equipment, if applicable.	3.4
A-1-14	The observable shall be converted to an equipment-independent quantity, e.g. frequencies shall be reported at the ‘sky level’ (i.e., actual transmitted/received frequencies).	3.4
A-1-15	Other corrections applied to the data, such as media corrections, shall be agreed upon by the service-providing and the customer Agencies via an ICD.	4.5
A-1-16	The data transfer mechanism shall not place constraints on the tracking data content.	1.2

¹ SANA may have upcoming standards in this area.

Table A-2: Heritage Requirements

	<u>Requirement</u>	<u>Trace</u>
A-2-1	The standard shall be, or must include, an ASCII format.	4.2
A-2-2	The standard shall not require software supplied by other agencies.	3, 4.2

Table A-3: Desirable Characteristics

<u>ID</u>	<u>Requirement</u>	<u>Trace</u>
A-3-1	The standard should apply to non-traditional objects, such as landers, rovers, balloons, spacecraft-spacecraft tracking data exchange, etc.	3.3, 3.4
A-3-2	The standard should be extensible with no disruption to existing users/uses.	3.1.3
A-3-3	Keywords, values, and terminology in the TDM should be the same as those in the ODM and ADM, where applicable.	3.1.3, 3.3, 3.4, 4.5
A-3-4	The standard shall not preclude an XML implementation.	2

ANNEX B

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

In several places in this document there are references to items which should be specified in an Interface Control Document (ICD) between agencies participating in an exchange of tracking data, if they are applicable to the particular exchange. The ICD should be jointly produced by both Agencies participating in a cross-support activity involving the collection, analysis and transfer of tracking data. This section compiles those items into a single location.

The greater the amount of material specified via ICD, the lesser the utility/benefit of the TDM (custom programming may be required to tailor software for each ICD). It is suggested to avoid a large number of items specified via ICD, to ensure full utility/benefit of the TDM.

From an implementation standpoint, it is probable that many of the items that need to be negotiated via ICD will be introduced into the system that processes tracking data via one or more configuration files that specify the settings of specific, related parameters that will be used during the tracking session, for example, the name of the time system to be used for the tracking data. This may vary between exchange participants. Different versions of programs could be used to prepare the tracking data where these parameters differ; however, a more efficient design would be to have a single program that is configured based on tracking pass-specific information. It seems likely that there may be at least two configuration files necessary, one which contains Agency-specific parameters that do not change between tracking passes, and one which contains spacecraft/mission specific parameters that could change with every tracking pass.

Another thought on ICDs is that it might be feasible for participating agencies to have a generic baseline ICD ('standard service provider ICD') that specifies mission/spacecraft independent entities on the interface, e.g., those associated with the agency's ground antennas (axis offsets, station locations, side motions, reference frame, epoch, supported frequency bands, etc.). Then smaller ICDs could be used for the mission/spacecraft specific arrangements.

The following table lists the items that should be covered in an ICD, along with where they are discussed in the text:

Item	Section
1. Definition of accuracy requirements pertaining to any particular TDM.	1.2
2. Method of exchanging TDMs.	1.2, 2.2
3. Interagency Information Technology (IT) security requirements in TDMs.	1.6
4. TDM file naming conventions.	2.2
5. Conditions under which multiple TDMs will be exchanged (e.g., launch supports with periodic TDMs; critical maneuvers, orbit insertions, etc.).	2.3
6. Specific TDM version number(s) that will be exchanged.	3.1.3
7. List of valid values that may be used for 'ORIGINATOR' keyword in the TDM Header.	3.1.3
8. Antenna geometry, if not accommodated by built-in values of 'ANTENNA_FRAME' keyword.	3.3
9. The list of eligible names that is used for PARTICIPANT keywords.	3.3
10. Definitions of 'raw', 'validated', and 'degraded' as they apply to data quality for a particular exchange.	3.3
11. If more than five participants are necessary, special arrangements are necessary.	3.3.6
12. When all the data in a TDM segment is media related or weather related, then the value of the MODE keyword is 'N/A'. Data of this type may be relative to a reference location within the tracking complex; the Methods used to extrapolate the measurements to other antennas should be specified in the ICD.	3.3.9
13. Complete description of the station location(s), including the antenna coordinates with their defining system, plate motion, and the relative geometry of the tracking point and cross axis of the antenna mount, accommodations for antenna tilt to avoid keyhole problems, etc. The station location could be provided via an OPM (reference [4]). Antenna geometry would be necessary for exceptional cases, where the station location is not fixed during track, for example.	3.4
14. Standard corrections that will (or will not) be applied to the data (e.g., tropospheric, meteorological, media, transponder, etc.).	3.4
15. Spin correction arrangements (who will do the correction... the agency providing the tracking or the agency that operates the spacecraft). Spin corrections should be applied by the OPERATOR of the spacecraft.	3.4
16. Definition of the range unit.	3.5.2.4
17. Equation for calculation of four-way Doppler shift, if applicable.	3.5.2.5

Item	Section
18. Transponder turnaround ratios necessary to calculate predicted downlink frequency and the Doppler measurement; also includes cases such as dual uplink where a 'beacon' or 'pilot' frequency is used (e.g., TDRS, DRTS, COMETS).	3.5.2.5, 3.5.2.6
19. Elevation mapping function for the tropospheric data.	3.5.5.2
20. Recommended polynomial interpolations for tropospheric data.	3.5.5.2
21. If non-standard floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required in an ICD between participating agencies.	4.3
22. Information which must appear in comments for any given TDM exchange.	4.5
23. Description of any ancillary data not already included in the Tracking Data Record definition.	4.5
24. Correction algorithms that are more complex than a simple scalar value.	N/A
25. Whether the ASCII or XML format of the TDM will be exchanged. ¹	N/A

¹ Currently the XML implementation does not exist, so the only format that can be exchanged is the ASCII version).

ANNEX C

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
AZEL	Azimuth-Elevation
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee on Space Data Systems
DSS	Deep Space Station
GPS	Global Positioning System
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
K	Kelvin
KVN	Keyword = Value notation
MOIMS	Mission Operations and Information Management Services
N/A	Not Applicable / Not Available
ODM	Orbit Data Message
OPM	Orbit Parameter Message
Pr/No	Ranging Power to Noise Spectral Density ratio
RADEC	Right Ascension-Declination
SANA	Space Assigned Numbers Authority
SCLK	Spacecraft Clock
SFTP	Secure File Transfer Protocol
TDM	Tracking Data Message
TEC	Total Electron Count
TECU	Total Electron Count Units
UTC	Coordinated Universal Time
VLBI	Very Long Baseline Interferometry
XEYN	X:East, Y:North
XS YE	X:South, Y:East
XML	eXtensible Markup Language

ANNEX D

EXAMPLE TRACKING DATA MESSAGES

(INFORMATIVE)

This annex will explain various tracking data scenarios and how they may be expressed in the Tracking Data Message.¹

Table D-1 below provides suggestions as to the metadata and data keywords that may be useful for specific measurement scenarios. In some cases, particular keyword settings are included. In most cases, these are not requirements; however, they may assist the user in constructing a TDM that captures the data from a specific measurement session.

¹ As of TDM version 1.0, this annex is still under development.

Table D-1: Measurement Specific Keywords and Settings

Data Type	Metadata Keywords	Data Keywords
Range	CORRECTION_RANGE DATA_QUALITY PATH INTEGRATION_REF MODE=SEQUENTIAL RANGE_MODE RANGE_MODULUS RANGE_UNITS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS RANGE_RATE RANGE_SNR TRANSMIT_FREQ TRANSMIT_FREQ_RATE CLOCK_BIAS CLOCK_DRIFT
Differenced Range	CORRECTION_RANGE DATA_QUALITY DIFF_MODE MODE=SINGLE-DIFF PATH RANGE_MODULUS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS TRANSMIT_FREQ
Doppler	INTEGRATION_INTERVAL CORRECTION_DOPPLER DATA_QUALITY FREQ_OFFSET INTEGRATION_REF MODE=SEQUENTIAL PATH RECEIVE_DELAY_n TRANSMIT_DELAY_n	TRANSMIT_FREQ TRANSMIT_FREQ_RATE RECEIVE_FREQ CLOCK_BIAS CLOCK_DRIFT
Differenced Doppler	INTEGRATION_INTERVAL CORRECTION_DOPPLER DATA_QUALITY DIFF_MODE INTEGRATION_REF MODE=SINGLE-DIFF RECEIVE_DELAY_n TRANSMIT_DELAY_n	RECEIVE_FREQ CLOCK_BIAS CLOCK_DRIFT
Delta-DOR	INTEGRATION_INTERVAL DATA_QUALITY DIFF_MODE INTEGRATION_REF MODE=DOUBLE-DIFF RANGE_MODE RANGE_MODULUS RANGE_UNITS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS TRANSMIT_FREQ CLOCK_BIAS CLOCK_DRIFT
Meteorological	DATA_QUALITY MODE=N/A	HUMIDITY PRESSURE TEMPERATURE

Data Type	Metadata Keywords	Data Keywords
Media	DATA_QUALITY MODE=N/A CORRECTION_TROPO_DRY CORRECTION_TROPO_WET CORRECTION_CP	CPDELAY TROPO_DRY TROPO_WET
Time Related (clock bias and drift)	DATA_QUALITY MODE=N/A	CLOCK_BIAS CLOCK_DRIFT
Angles	ANGLE_TYPE CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 DATA_QUALITY MODE=SEQUENTIAL PATH REFERENCE_FRAME	ANGLE_1 ANGLE_2

The figures on the following pages are example Tracking Data Messages. For actual TDMs, the ratio of tracking data to metadata will probably be higher than appears in these samples. Also, many of the examples portray a single data type; however, the TDM Recommended Standard does not require this: any of the keywords can appear in the same TDM data segment, as long as the associated metadata accurately provides the context.

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-160T20:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down

META_START
COMMENT Data quality degraded by antenna pointing problem... slightly noisy
data
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0
TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
DATA_QUALITY = DEGRADED
META_STOP

DATA_START
TRANSMIT_FREQ_2 = 2005-159T17:41:00      32023442781.733
RECEIVE_FREQ_1 = 2005-159T17:41:00      32021034790.7265
RECEIVE_FREQ_1 = 2005-159T17:41:01      32021034828.8432
RECEIVE_FREQ_1 = 2005-159T17:41:02      32021034866.9449
RECEIVE_FREQ_1 = 2005-159T17:41:03      32021034905.0327
RECEIVE_FREQ_1 = 2005-159T17:41:04      32021034943.0946
RECEIVE_FREQ_1 = 2005-159T17:41:05      32021034981.2049
RECEIVE_FREQ_1 = 2005-159T17:41:06      32021035019.2778
RECEIVE_FREQ_1 = 2005-159T17:41:07      32021035057.3773
RECEIVE_FREQ_1 = 2005-159T17:41:08      32021035095.4377
RECEIVE_FREQ_1 = 2005-159T17:41:09      32021035133.5604
RECEIVE_FREQ_1 = 2005-159T17:41:10      32021035171.5861
RECEIVE_FREQ_1 = 2005-159T17:41:11      32021035209.6653
RECEIVE_FREQ_1 = 2005-159T17:41:12      32021035247.7804
RECEIVE_FREQ_1 = 2005-159T17:41:13      32021035285.8715
RECEIVE_FREQ_1 = 2005-159T17:41:14      32021035323.8187
RECEIVE_FREQ_1 = 2005-159T17:41:15      32021035361.9571
RECEIVE_FREQ_1 = 2005-159T17:41:16      32021035400.0304
RECEIVE_FREQ_1 = 2005-159T17:41:17      32021035438.0126
RECEIVE_FREQ_1 = 2005-159T17:41:18      32021035476.1241
RECEIVE_FREQ_1 = 2005-159T17:41:19      32021035514.1714
RECEIVE_FREQ_1 = 2005-159T17:41:20      32021035552.2263
RECEIVE_FREQ_1 = 2005-159T17:41:21      32021035590.2671
RECEIVE_FREQ_1 = 2005-159T17:41:22      32021035628.304
RECEIVE_FREQ_1 = 2005-159T17:41:23      32021035666.3579
RECEIVE_FREQ_1 = 2005-159T17:41:24      32021035704.3745
RECEIVE_FREQ_1 = 2005-159T17:41:25      32021035742.4425
RECEIVE_FREQ_1 = 2005-159T17:41:26      32021035780.4974
RECEIVE_FREQ_1 = 2005-159T17:41:27      32021035818.5158
RECEIVE_FREQ_1 = 2005-159T17:41:28      32021035856.5721
RECEIVE_FREQ_1 = 2005-159T17:41:29      32021035894.5601
RECEIVE_FREQ_1 = 2005-159T17:41:30      32021035932.5939
RECEIVE_FREQ_1 = 2005-159T17:41:31      32021035970.6275
RECEIVE_FREQ_1 = 2005-159T17:41:32      32021036008.6377
RECEIVE_FREQ_1 = 2005-159T17:41:33      32021036046.6657
RECEIVE_FREQ_1 = 2005-159T17:41:34      32021036084.6911
RECEIVE_FREQ_1 = 2005-159T17:41:35      32021036122.689
RECEIVE_FREQ_1 = 2005-159T17:41:36      32021036160.7083
RECEIVE_FREQ_1 = 2005-159T17:41:37      32021036198.7493
RECEIVE_FREQ_1 = 2005-159T17:41:38      32021036236.7388
RECEIVE_FREQ_1 = 2005-159T17:41:39      32021036274.7529
RECEIVE_FREQ_1 = 2005-159T17:41:40      32021036312.7732
DATA_STOP

```

Figure D-1: TDM Example: One-Way Data

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-160T20:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down
COMMENT Data quality degraded by antenna pointing problem... slightly noisy
data

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 32021035200
TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
DATA_QUALITY = DEGRADED
META_STOP

DATA_START
COMMENT Units provided in this example
TRANSMIT_FREQ_2 = 2005-159T17:41:00 32023442781.733 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:00 -409.2735 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:01 -371.1568 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:02 -333.0551 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:03 -294.9673 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:04 -256.9054 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:05 -218.7951 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:06 -180.7222 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:07 -142.6227 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:08 -104.5623 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:09 -66.4396 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:10 -28.4139 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:11 9.6653 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:12 47.7804 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:13 85.8715 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:14 123.8187 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:15 161.9571 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:16 200.0304 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:17 238.0126 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:18 276.1241 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:19 314.1714 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:20 352.2263 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:21 390.2671 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:22 428.3040 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:23 466.3579 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:24 504.3745 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:25 542.4425 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:26 580.4974 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:27 618.5158 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:28 656.5721 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:29 694.5601 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:30 732.5939 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:31 770.6275 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:32 808.6377 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:33 846.6657 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:34 884.6911 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:35 922.6890 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:36 960.7083 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:37 998.7493 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:38 1036.7388 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:39 1074.7529 [HZ]
RECEIVE_FREQ_1 = 2005-159T17:41:40 1112.7732 [HZ]
DATA_STOP

```

Figure D-2: TDM Example: One-Way Data w/Frequency Offset

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-184T20:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyyy-nnnA Nav Team (NASA/JPL)

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0
START_TIME = 2005-184T11:12:23
STOP_TIME = 2005-184T13:59:48.27
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-184T11:12:23      7175173383.615373
TRANSMIT_FREQ_1 = 2005-184T11:12:24      7175173384.017573
TRANSMIT_FREQ_1 = 2005-184T11:12:25      7175173384.419773
TRANSMIT_FREQ_1 = 2005-184T11:12:26      7175173384.821973
TRANSMIT_FREQ_1 = 2005-184T11:12:27      7175173385.224173
TRANSMIT_FREQ_1 = 2005-184T11:12:28      7175173385.626373
TRANSMIT_FREQ_1 = 2005-184T11:12:29      7175173386.028573
TRANSMIT_FREQ_1 = 2005-184T11:12:30      7175173386.430773
TRANSMIT_FREQ_1 = 2005-184T11:12:31      7175173386.832973
TRANSMIT_FREQ_1 = 2005-184T11:12:32      7175173387.235173
TRANSMIT_FREQ_1 = 2005-184T11:12:33      7175173387.637373
TRANSMIT_FREQ_1 = 2005-184T11:12:34      7175173388.039573
TRANSMIT_FREQ_1 = 2005-184T11:12:35      7175173388.441773
TRANSMIT_FREQ_1 = 2005-184T11:12:36      7175173388.843973
TRANSMIT_FREQ_1 = 2005-184T11:12:37      7175173389.246173
TRANSMIT_FREQ_1 = 2005-184T11:12:38      7175173389.648373
TRANSMIT_FREQ_1 = 2005-184T11:12:39      7175173390.050573
TRANSMIT_FREQ_1 = 2005-184T11:12:40      7175173390.452773
TRANSMIT_FREQ_1 = 2005-184T11:12:41      7175173390.854973
TRANSMIT_FREQ_1 = 2005-184T11:12:42      7175173391.257173
TRANSMIT_FREQ_1 = 2005-184T11:12:43      7175173391.659373
TRANSMIT_FREQ_1 = 2005-184T11:12:44      7175173392.061573
RECEIVE_FREQ_1 = 2005-184T13:59:27.27      8429753135.986102
RECEIVE_FREQ_1 = 2005-184T13:59:28.27      8429749428.196568
RECEIVE_FREQ_1 = 2005-184T13:59:29.27      8429749427.584727
RECEIVE_FREQ_1 = 2005-184T13:59:30.27      8429749427.023103
RECEIVE_FREQ_1 = 2005-184T13:59:31.27      8429749426.346252
RECEIVE_FREQ_1 = 2005-184T13:59:32.27      8429749425.738658
RECEIVE_FREQ_1 = 2005-184T13:59:33.27      8429749425.113143
RECEIVE_FREQ_1 = 2005-184T13:59:34.27      8429749424.489933
RECEIVE_FREQ_1 = 2005-184T13:59:35.27      8429749423.876996
RECEIVE_FREQ_1 = 2005-184T13:59:36.27      8429749423.325228
RECEIVE_FREQ_1 = 2005-184T13:59:37.27      8429749422.664049
RECEIVE_FREQ_1 = 2005-184T13:59:38.27      8429749422.054996
RECEIVE_FREQ_1 = 2005-184T13:59:39.27      8429749421.425801
RECEIVE_FREQ_1 = 2005-184T13:59:40.27      8429749420.824186
RECEIVE_FREQ_1 = 2005-184T13:59:41.27      8429749420.204178
RECEIVE_FREQ_1 = 2005-184T13:59:42.27      8429749419.596043
RECEIVE_FREQ_1 = 2005-184T13:59:43.27      8429749418.986191
RECEIVE_FREQ_1 = 2005-184T13:59:44.27      8429749418.356392
RECEIVE_FREQ_1 = 2005-184T13:59:45.27      8429749417.791263
RECEIVE_FREQ_1 = 2005-184T13:59:46.27      8429749417.142501
RECEIVE_FREQ_1 = 2005-184T13:59:47.27      8429749416.544415
RECEIVE_FREQ_1 = 2005-184T13:59:48.27      8429749415.910163
DATA_STOP

```

Figure D-3: TDM Example: Two-Way Frequency Data for Doppler Calculation

```

CCSDS_TDM_VERSION = 1.0
CREATION_DATE = 2005-191T23:00:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)

META_START
COMMENT Range correction applied is range calibration to DSS-24.
COMMENT Estimated RTLT at begin of pass = 950 seconds
COMMENT Antenna Z-height correction 1.8183e-07 s applied to uplink signal path
COMMENT Antenna Z-height correction 6.3141e-08 s applied to downlink signal path

TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-24
PARTICIPANT_2 = yyyyy-nnnA
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_REF = START
RANGE_MODE = COHERENT
RANGE_MODULUS = 2e+26
RANGE_UNITS = RU
TRANSMIT_DELAY_1 = 7.7e-5
TRANSMIT_DELAY_2 = 0
RECEIVE_DELAY_1 = 7.7e-5
RECEIVE_DELAY_2 = 0
START_TIME = 2005-191T00:31:51
STOP_TIME = 2005-191T01:13:09
CORRECTION_RANGE = 164927.69
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-191T00:31:51 7180064367.3536
RANGE_OBS = 2005-191T00:31:51 39242998.5151986
RANGE_SNR = 2005-191T00:31:51 28.52538
TRANSMIT_FREQ_1 = 2005-191T00:34:48 7180064472.3146
RANGE_OBS = 2005-191T00:34:48 61172265.3115234
RANGE_SNR = 2005-191T00:34:48 28.39347
TRANSMIT_FREQ_1 = 2005-191T00:37:45 7180064577.2756
RANGE_OBS = 2005-191T00:37:45 15998108.8168328
RANGE_SNR = 2005-191T00:37:45 28.16193
TRANSMIT_FREQ_1 = 2005-191T00:40:42 7180064682.2366
RANGE_OBS = 2005-191T00:40:42 37938284.4138008
RANGE_SNR = 2005-191T00:40:42 29.44597
TRANSMIT_FREQ_1 = 2005-191T00:43:39 7180064787.1976
RANGE_OBS = 2005-191T00:43:39 59883968.0697146
RANGE_SNR = 2005-191T00:43:39 27.44037
TRANSMIT_FREQ_1 = 2005-191T00:46:36 7180064894.77345
RANGE_OBS = 2005-191T00:46:36 14726355.3958799
RANGE_SNR = 2005-191T00:46:36 27.30462
TRANSMIT_FREQ_1 = 2005-191T00:49:33 7180065002.72044
RANGE_OBS = 2005-191T00:49:33 36683224.3750253
RANGE_SNR = 2005-191T00:49:33 28.32537
TRANSMIT_FREQ_1 = 2005-191T00:52:30 7180065110.66743
RANGE_OBS = 2005-191T00:52:30 58645699.4734682
RANGE_SNR = 2005-191T00:52:30 29.06158
TRANSMIT_FREQ_1 = 2005-191T00:55:27 7180065218.61442
RANGE_OBS = 2005-191T00:55:27 13504948.3585422
RANGE_SNR = 2005-191T00:55:27 27.29589
TRANSMIT_FREQ_1 = 2005-191T00:58:24 7180065326.56141
RANGE_OBS = 2005-191T00:58:24 35478729.4012973
RANGE_SNR = 2005-191T00:58:24 30.48199
TRANSMIT_FREQ_1 = 2005-191T01:01:21 7180065436.45167
RANGE_OBS = 2005-191T01:01:21 57458219.0681689
RANGE_SNR = 2005-191T01:01:21 27.15509
TRANSMIT_FREQ_1 = 2005-191T01:10:12 7180065768.96387
RANGE_OBS = 2005-191T01:10:12 56322324.0168757
RANGE_SNR = 2005-191T01:10:12 28.73831
TRANSMIT_FREQ_1 = 2005-191T01:13:09 7180065879.80127
RANGE_OBS = 2005-191T01:13:09 11216037.9857342
RANGE_SNR = 2005-191T01:13:09 28.63882
DATA_STOP

```

Figure D-4: TDM Example: Two-Way Ranging Data Only

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-184T20:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyyy-nnnA Nav Team (NASA/JPL)

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = yyyyy-nnnA
PARTICIPANT_3 = DSS-25
MODE = SEQUENTIAL
PATH = 1,2,3
TIMETAG_REF = RECEIVE

INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
START_TIME = 2005-184T11:12:23
STOP_TIME = 2005-184T13:59:48.27
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-184T11:12:23 7175173383.615373
RECEIVE_FREQ_3 = 2005-184T13:59:27.27 8429753135.986102
TRANSMIT_FREQ_1 = 2005-184T11:12:24 7175173384.017573
RECEIVE_FREQ_3 = 2005-184T13:59:28.27 8429749428.196568
TRANSMIT_FREQ_1 = 2005-184T11:12:25 7175173384.419773
RECEIVE_FREQ_3 = 2005-184T13:59:29.27 8429749427.584727
TRANSMIT_FREQ_1 = 2005-184T11:12:26 7175173384.821973
RECEIVE_FREQ_3 = 2005-184T13:59:30.27 8429749427.023103
TRANSMIT_FREQ_1 = 2005-184T11:12:27 7175173385.224173
RECEIVE_FREQ_3 = 2005-184T13:59:31.27 8429749426.346252
TRANSMIT_FREQ_1 = 2005-184T11:12:28 7175173385.626373
RECEIVE_FREQ_3 = 2005-184T13:59:32.27 8429749425.738658
TRANSMIT_FREQ_1 = 2005-184T11:12:29 7175173386.028573
RECEIVE_FREQ_3 = 2005-184T13:59:33.27 8429749425.113143
TRANSMIT_FREQ_1 = 2005-184T11:12:30 7175173386.430773
RECEIVE_FREQ_3 = 2005-184T13:59:34.27 8429749424.489933
TRANSMIT_FREQ_1 = 2005-184T11:12:31 7175173386.832973
RECEIVE_FREQ_3 = 2005-184T13:59:35.27 8429749423.876996
TRANSMIT_FREQ_1 = 2005-184T11:12:32 7175173387.235173
RECEIVE_FREQ_3 = 2005-184T13:59:36.27 8429749423.325228
TRANSMIT_FREQ_1 = 2005-184T11:12:33 7175173387.637373
RECEIVE_FREQ_3 = 2005-184T13:59:37.27 8429749422.664049
TRANSMIT_FREQ_1 = 2005-184T11:12:34 7175173388.039573
RECEIVE_FREQ_3 = 2005-184T13:59:38.27 8429749422.054996
TRANSMIT_FREQ_1 = 2005-184T11:12:35 7175173388.441773
RECEIVE_FREQ_3 = 2005-184T13:59:39.27 8429749421.425801
TRANSMIT_FREQ_1 = 2005-184T11:12:36 7175173388.843973
RECEIVE_FREQ_3 = 2005-184T13:59:40.27 8429749420.824186
TRANSMIT_FREQ_1 = 2005-184T11:12:37 7175173389.246173
RECEIVE_FREQ_3 = 2005-184T13:59:41.27 8429749420.204178
TRANSMIT_FREQ_1 = 2005-184T11:12:38 7175173389.648373
RECEIVE_FREQ_3 = 2005-184T13:59:42.27 8429749419.596043
TRANSMIT_FREQ_1 = 2005-184T11:12:39 7175173390.050573
RECEIVE_FREQ_3 = 2005-184T13:59:43.27 8429749418.986191
TRANSMIT_FREQ_1 = 2005-184T11:12:40 7175173390.452773
RECEIVE_FREQ_3 = 2005-184T13:59:44.27 8429749418.356392
TRANSMIT_FREQ_1 = 2005-184T11:12:41 7175173390.854973
RECEIVE_FREQ_3 = 2005-184T13:59:45.27 8429749417.791263
TRANSMIT_FREQ_1 = 2005-184T11:12:42 7175173391.257173
RECEIVE_FREQ_3 = 2005-184T13:59:46.27 8429749417.142501
TRANSMIT_FREQ_1 = 2005-184T11:12:43 7175173391.659373
RECEIVE_FREQ_3 = 2005-184T13:59:47.27 8429749416.544415
TRANSMIT_FREQ_1 = 2005-184T11:12:44 7175173392.061573
RECEIVE_FREQ_3 = 2005-184T13:59:48.27 8429749415.910163
DATA_STOP

```

Figure D-5: TDM Example: Three-Way Frequency Data

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 1998-06-10T01:00:00
ORIGINATOR = JAXA

COMMENT TDM example created by yyyyy-nnnA Nav Team (JAXA)

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = NORTH
PARTICIPANT_2 = F07R07
PARTICIPANT_3 = E7
MODE = SEQUENTIAL
PATH = 1,2,3,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
RANGE_UNITS = KM
ANGLE_TYPE = AZEL
START_TIME = 1998-06-10T00:57:37
STOP_TIME = 1998-06-10T00:57:44
META_STOP

DATA_START
RANGE_OBS = 10-JUN-1998T00:57:37 80452.7542
RANGE_RATE = 10-JUN-1998T00:57:37 924.355
ANGLE_1 = 10-JUN-1998T00:57:37 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:37 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:37 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:38 80452.7368
RANGE_RATE = 10-JUN-1998T00:57:38 924.354
ANGLE_1 = 10-JUN-1998T00:57:38 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:38 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:38 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:39 80452.7197
RANGE_RATE = 10-JUN-1998T00:57:39 924.279
ANGLE_1 = 10-JUN-1998T00:57:39 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:39 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:39 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:40 80452.7025
RANGE_RATE = 10-JUN-1998T00:57:40 924.267
ANGLE_1 = 10-JUN-1998T00:57:40 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:40 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:40 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:41 80452.6854
RANGE_RATE = 10-JUN-1998T00:57:41 924.224
ANGLE_1 = 10-JUN-1998T00:57:41 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:41 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:41 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:42 80452.6680
RANGE_RATE = 10-JUN-1998T00:57:42 924.190
ANGLE_1 = 10-JUN-1998T00:57:42 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:42 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:42 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:43 80452.6503
RANGE_RATE = 10-JUN-1998T00:57:43 924.163
ANGLE_1 = 10-JUN-1998T00:57:43 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:43 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:43 2287487999.0

RANGE_OBS = 10-JUN-1998T00:57:44 80452.6331
RANGE_RATE = 10-JUN-1998T00:57:44 924.109
ANGLE_1 = 10-JUN-1998T00:57:44 256.64002393
ANGLE_2 = 10-JUN-1998T00:57:44 13.38100016
RECEIVE_FREQ = 10-JUN-1998 00:57:44 2287487999.0
DATA_STOP

```

Figure D-6: TDM Example: Four-Way Data

The next example TDM describes a scenario such as might occur with a spacecraft like Cassini, which has 3 transponders: X/S, X/X, X/Ka. In this scenario, a tracking session in which all 3 transponders were used requires a TDM with 3 segments. This is because a single segment would have duplications of keyword and timetag in the same segment, given the S-down, X-down, and Ka-down measurements at the same time tags. A single TDM segment could be coded with five participants (Cassini S-down, X-down, and Ka-down transponders as the spacecraft participants, and the two ground antennas). However, it would not be possible to specify a 'PATH' statement that would meet this scenario.

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2003-268T20:15:00
ORIGINATOR = NASA/JPL
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT This example is still in progress.

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-X
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2003-268T13:12:10
STOP_TIME = 2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2003-268T13:12:10 7123456789.000000
RECEIVE_FREQ_1 = 2003-268T13:12:30 8369351234.567890
RECEIVE_FREQ_1 = 2003-268T13:13:30 8369351245.567890
RECEIVE_FREQ_1 = 2003-268T13:14:30 8369351256.567890
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-KA
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2003-268T13:12:10
STOP_TIME = 2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2003-268T13:12:10 7123456789.000000
RECEIVE_FREQ_1 = 2003-268T13:12:30 32369351234.567890
RECEIVE_FREQ_1 = 2003-268T13:13:30 32369351245.567890
RECEIVE_FREQ_1 = 2003-268T13:14:30 32369351256.567890
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-S
PARTICIPANT_3 = DSS-24
MODE = SEQUENTIAL
PATH = 1,2,3
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 7.7e-5
RECEIVE_DELAY_3 = 7.6e-5
START_TIME = 2003-268T13:12:10
STOP_TIME = 2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2003-268T13:12:10 7123456789.000000
RECEIVE_FREQ_3 = 2003-268T13:12:30 2282549571.91
RECEIVE_FREQ_3 = 2003-268T13:13:30 2282549671.91
RECEIVE_FREQ_3 = 2003-268T13:14:30 2282549771.91
DATA_STOP

```

Figure D-7: TDM Example: One S/C, X-up, S-down, X-down, Ka-down, Three Segments

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT This TDM example contains single differenced range data.

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-25
PARTICIPANT_3 = DSS-55
MODE = SINGLE-DIFF
DIFF MODE = RANGE
TIMETAG_REF = RECEIVE
RANGE_MODE = COHERENT
RANGE_MODULUS = 1.616485E+02
RANGE_UNITS = S
TRANSMIT_DELAY_2 = .000077
RECEIVE_DELAY_2 = .000077
START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
RANGE_OBS = 2004-136T15:30:00.0000 -2.563490649E-03
TRANSMIT_FREQ_2 = 2004-136T15:42:00.0000 7.156430612053E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000 -4.59e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000 -2.953e-6
DATA_STOP

```

Figure D-8: TDM Example: Differenced Range Observable

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT This TDM example contains single differenced Doppler data.

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-25
PARTICIPANT_3 = DSS-55
MODE = SINGLE-DIFF
DIFF MODE = DELAY
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 580
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_2 = .000077
RECEIVE_DELAY_2 = .000077
START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
TRANSMIT_FREQ_2 = 2004-136T15:30:00.0000 7.156430845899E+09
RECEIVE_FREQ = 2004-136T15:30:00.0000 15100.837278
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000 -4.59e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000 -2.953e-6
DATA_STOP

```

Figure D-9: TDM Example: Differenced Doppler Observable

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT This TDM example contains single differenced Doppler data.
COMMENT This example still in progress.

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-25
PARTICIPANT_3 = DSS-55
MODE = SINGLE-DIFF
DIFF_MODE = DELAY
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 580
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_2 = .000077
RECEIVE_DELAY_2 = .000077
START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A
TIMETAG_REF = RECEIVE
START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A
TIMETAG_REF = RECEIVE
START_TIME = 2004-136T15:30:00.0000
STOP_TIME = 2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_STOP

```

Figure D-10: TDM Example: Differenced Doppler Observable¹

¹ Waiting for some differenced spacecraft to spacecraft Doppler data... [figure] is same as [previous] example.

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT This TDM example contains delta-DOR data.
COMMENT Quasar CTD 20 also known as J023752.4+284808 (ICRF) and 0234+285 (IERS)

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = CTD 20
PARTICIPANT_3 = DSS-25
PARTICIPANT_4 = DSS-55
MODE = DOUBLE-DIFF
DIFF_MODE = RANGE
TIMETAG_REF = RECEIVE
RANGE_MODE = COHERENT
RANGE_MODULUS = 1.674852710000000E+02
RANGE_UNITS = S
TRANSMIT_DELAY_3 = .000077
RECEIVE_DELAY_3 = .000077
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
RANGE_OBS = 2004-136T15:42:00.0000 -4.911896106591159E+06
TRANSMIT_FREQ_3 = 2004-136T15:42:00.0000 7.156430830844751E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:42:00.0000 -4.59e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:42:00.0000 -2.953e-6
DATA_STOP

```

Figure D-11: TDM Example: delta-DOR Observable

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-157T18:25:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek: one minute of launch angles from DSS-16

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-16
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
TIMETAG_REF = RECEIVE
ANGLE_TYPE = XSYE
START_TIME = 2004-216T07:44:00
STOP_TIME = 2004-216T07:45:00
META_STOP

DATA_START

ANGLE_1 = 2004-216T07:44:00 -23.62012
ANGLE_2 = 2004-216T07:44:00 -73.11035

ANGLE_1 = 2004-216T07:44:10 -23.04004
ANGLE_2 = 2004-216T07:44:10 -72.74316

ANGLE_1 = 2004-216T07:44:20 -22.78125
ANGLE_2 = 2004-216T07:44:20 -72.53027

ANGLE_1 = 2004-216T07:44:30 -22.59180
ANGLE_2 = 2004-216T07:44:30 -72.37598

ANGLE_1 = 2004-216T07:44:40 -22.40527
ANGLE_2 = 2004-216T07:44:40 -72.23730

ANGLE_1 = 2004-216T07:44:50 -22.23047
ANGLE_2 = 2004-216T07:44:50 -72.08887

ANGLE_1 = 2004-216T07:45:00 -22.08984
ANGLE_2 = 2004-216T07:45:00 -71.93750

DATA_STOP
```

Figure D-12: TDM Example: Angle Data Only

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-223T23:00:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by NASA/JPL Navigation System Engineering

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-14
MODE = N/A
START_TIME = 2005-275T12:00:00
STOP_TIME = 2005-280T12:00:00
META_STOP

DATA_START
COMMENT Elevation mapping function is Niell model
TROPO_DRY = 2005-274T12:00:00 2.0526
TROPO_DRY = 2005-275T12:00:00 2.0530 [m]
TROPO_DRY = 2005-276T12:00:00 2.0533 [m]
TROPO_DRY = 2005-277T12:00:00 2.0537 [m]
TROPO_DRY = 2005-278T12:00:00 2.0540 [m]
TROPO_DRY = 2005-279T12:00:00 2.0544 [m]
TROPO_DRY = 2005-280T12:00:00 2.0547 [m]

TROPO_WET = 2005-274T12:00:00 0.1139
TROPO_WET = 2005-275T12:00:00 0.1126
TROPO_WET = 2005-276T12:00:00 0.1113
TROPO_WET = 2005-277T12:00:00 0.1099
TROPO_WET = 2005-278T12:00:00 0.1086
TROPO_WET = 2005-279T12:00:00 0.1074
TROPO_WET = 2005-280T12:00:00 0.1061
DATA_STOP

META_START
COMMENT Line of vertical ionospheric calibration for yyyy-nnnA
COMMENT Time tags are end time of 15 minute measurement interval
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-10
MODE = N/A
START_TIME = 2005-280T21:45:00
STOP_TIME = 2005-281T00:00:00
META_STOP

DATA_START

CPDELAY = 2005-280T21:45:00 23.1 [TECU]
CPDELAY = 2005-280T22:00:00 22.8 [TECU]
CPDELAY = 2005-280T22:15:00 23.2 [TECU]
CPDELAY = 2005-280T22:30:00 24.4 [TECU]
CPDELAY = 2005-280T22:45:00 23.6 [TECU]
CPDELAY = 2005-280T23:00:00 22.4 [TECU]
CPDELAY = 2005-280T23:15:00 22.6 [TECU]
CPDELAY = 2005-280T23:30:00 24.6 [TECU]
CPDELAY = 2005-280T23:45:00 24.0 [TECU]
CPDELAY = 2005-281T00:00:00 22.2 [TECU]
DATA_STOP

```

Figure D-13: TDM Example: Media Data Only

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T06:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT JPL/DSN/Goldstone (DSS-10) weather for 06/05/2005

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-10
MODE = N/A
START_TIME = 2005-156T00:03:00
STOP_TIME = 2005-156T06:03:00
META_STOP

DATA_START

TEMPERATURE = 2005-156T00:03:00 302.95 [K]
PRESSURE = 2005-156T00:03:00 896.2 [HPA]
RHUMIDITY = 2005-156T00:03:00 12.0 [%]

TEMPERATURE = 2005-156T00:33:00 304.05 [K]
PRESSURE = 2005-156T00:33:00 895.9 [HPA]
RHUMIDITY = 2005-156T00:33:00 11.0 [%]

TEMPERATURE = 2005-156T01:03:00 302.55 [K]
PRESSURE = 2005-156T01:03:00 895.7 [HPA]
RHUMIDITY = 2005-156T01:03:00 12.0 [%]

TEMPERATURE = 2005-156T01:33:00 302.65 [K]
PRESSURE = 2005-156T01:33:00 895.7 [HPA]
RHUMIDITY = 2005-156T01:33:00 11.0 [%]

TEMPERATURE = 2005-156T02:03:00 301.55 [K]
PRESSURE = 2005-156T02:03:00 895.9 [HPA]
RHUMIDITY = 2005-156T02:03:00 11.0 [%]

TEMPERATURE = 2005-156T02:33:00 300.45 [K]
PRESSURE = 2005-156T02:33:00 895.9 [HPA]
RHUMIDITY = 2005-156T02:33:00 12.0 [%]

TEMPERATURE = 2005-156T03:03:00 299.55 [K]
PRESSURE = 2005-156T03:03:00 896.1 [HPA]
RHUMIDITY = 2005-156T03:03:00 14.0 [%]

TEMPERATURE = 2005-156T03:33:00 298.65 [K]
PRESSURE = 2005-156T03:33:00 896.2 [HPA]
RHUMIDITY = 2005-156T03:33:00 15.0 [%]

TEMPERATURE = 2005-156T04:03:00 298.05 [K]
PRESSURE = 2005-156T04:03:00 896.4 [HPA]
RHUMIDITY = 2005-156T04:03:00 17.0 [%]

TEMPERATURE = 2005-156T04:33:00 297.15 [K]
PRESSURE = 2005-156T04:33:00 896.8 [HPA]
RHUMIDITY = 2005-156T04:33:00 19.0 [%]

TEMPERATURE = 2005-156T05:03:00 294.85 [K]
PRESSURE = 2005-156T05:03:00 897.3 [HPA]
RHUMIDITY = 2005-156T05:03:00 21.0 [%]

TEMPERATURE = 2005-156T05:33:00 293.95 [K]
PRESSURE = 2005-156T05:33:00 897.3 [HPA]
RHUMIDITY = 2005-156T05:33:00 23.0 [%]

TEMPERATURE = 2005-156T06:03:00 293.05 [K]
PRESSURE = 2005-156T06:03:00 897.3 [HPA]
RHUMIDITY = 2005-156T06:03:00 25.0 [%]

DATA_STOP

```

Figure D-14: TDM Example: Meteorological Data Only

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-161T15:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT The following are clock offsets, in seconds between the
COMMENT clocks at each DSN complex relative to UTC(NIST). The offset
COMMENT is a mean of readings using several GPS space vehicles in
COMMENT common view. Times assumed to be EOD. Value is "station clock
COMMENT minus UTC".

COMMENT Note: SPC10 switched back to Maser1 from Maser2 on 2005-142

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-10
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME = 2005-148T12:00:00
META_STOP

DATA_START
CLOCK_BIAS = 2005-142T12:00:00 9.56e-7
CLOCK_DRIFT = 2005-142T12:00:00 6.944e-14
CLOCK_BIAS = 2005-143T12:00:00 9.62e-7
CLOCK_DRIFT = 2005-143T12:00:00 -2.083e-13
CLOCK_BIAS = 2005-144T12:00:00 9.44e-7
CLOCK_DRIFT = 2005-144T12:00:00 -2.778e-13
CLOCK_BIAS = 2005-145T12:00:00 9.20e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-40
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME = 2005-148T12:00:00
META_STOP

DATA_START
CLOCK_BIAS = 2005-142T12:00:00 -7.40e-7
CLOCK_DRIFT = 2005-142T12:00:00 -3.125e-13
CLOCK_BIAS = 2005-143T12:00:00 -7.67e-7
CLOCK_DRIFT = 2005-143T12:00:00 -1.620e-13
CLOCK_BIAS = 2005-144T12:00:00 -7.81e-7
CLOCK_DRIFT = 2005-144T12:00:00 -4.745e-13
CLOCK_BIAS = 2005-145T12:00:00 -8.22e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-60
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME = 2005-148T12:00:00
META_STOP

DATA_START
CLOCK_BIAS = 2005-142T12:00:00 -1.782e-6
CLOCK_DRIFT = 2005-142T12:00:00 1.736e-13
CLOCK_BIAS = 2005-143T12:00:00 -1.767e-6
CLOCK_DRIFT = 2005-143T12:00:00 1.157e-14
CLOCK_BIAS = 2005-144T12:00:00 -1.766e-6
CLOCK_DRIFT = 2005-144T12:00:00 8.102e-14
CLOCK_BIAS = 2005-145T12:00:00 -1.759e-6
DATA_STOP

```

Figure D-15: TDM Example: Clock Bias/Drift Only

```

CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-65
PARTICIPANT_2 = yyyy-nnnA
MODE = N/A

START_TIME = 2005-157T08:22:46
STOP_TIME = 2005-157T18:54:53
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-157T08:22:46 7175516847.11634
TRANSMIT_FREQ_RATE_1 = 2005-157T08:22:46 0.29989
TRANSMIT_FREQ_1 = 2005-157T08:44:51 7175517244.46444
TRANSMIT_FREQ_RATE_1 = 2005-157T08:44:51 0.35889
TRANSMIT_FREQ_1 = 2005-157T09:05:48 7175517695.59096
TRANSMIT_FREQ_RATE_1 = 2005-157T09:05:48 0.41798
TRANSMIT_FREQ_1 = 2005-157T09:27:40 7175518243.98194
TRANSMIT_FREQ_RATE_1 = 2005-157T09:27:40 0.47836
TRANSMIT_FREQ_1 = 2005-157T09:49:39 7175518874.93938
TRANSMIT_FREQ_RATE_1 = 2005-157T09:49:39 0.53529
TRANSMIT_FREQ_1 = 2005-157T10:09:26 7175519510.33008
TRANSMIT_FREQ_RATE_1 = 2005-157T10:09:26 0.59170
TRANSMIT_FREQ_1 = 2005-157T10:31:48 7175520304.38500
TRANSMIT_FREQ_RATE_1 = 2005-157T10:31:48 0.65041
TRANSMIT_FREQ_1 = 2005-157T10:54:31 7175521190.89022
TRANSMIT_FREQ_RATE_1 = 2005-157T10:54:31 0.70797
TRANSMIT_FREQ_1 = 2005-157T11:17:44 7175522177.09923
TRANSMIT_FREQ_RATE_1 = 2005-157T11:17:44 0.76105
TRANSMIT_FREQ_1 = 2005-157T11:38:57 7175523145.91484
TRANSMIT_FREQ_RATE_1 = 2005-157T11:38:57 0.81257
TRANSMIT_FREQ_1 = 2005-157T12:03:36 7175524347.71014
TRANSMIT_FREQ_RATE_1 = 2005-157T12:03:36 0.86496
TRANSMIT_FREQ_1 = 2005-157T12:29:22 7175525684.93754
TRANSMIT_FREQ_RATE_1 = 2005-157T12:29:22 0.91200
TRANSMIT_FREQ_1 = 2005-157T12:53:35 7175527010.07869
TRANSMIT_FREQ_RATE_1 = 2005-157T12:53:35 0.95621
TRANSMIT_FREQ_1 = 2005-157T13:22:49 7175528687.26789
TRANSMIT_FREQ_RATE_1 = 2005-157T13:22:49 0.99899
TRANSMIT_FREQ_1 = 2005-157T13:55:19 7175530635.30759
TRANSMIT_FREQ_RATE_1 = 2005-157T13:55:19 1.03477
TRANSMIT_FREQ_1 = 2005-157T14:29:53 7175532781.42341
TRANSMIT_FREQ_RATE_1 = 2005-157T14:29:53 1.06353
TRANSMIT_FREQ_1 = 2005-157T15:24:49 7175536286.82686
TRANSMIT_FREQ_RATE_1 = 2005-157T15:24:49 1.07367
TRANSMIT_FREQ_1 = 2005-157T16:20:22 7175539865.36148
TRANSMIT_FREQ_RATE_1 = 2005-157T16:20:22 1.05186
TRANSMIT_FREQ_1 = 2005-157T17:00:34 7175542402.44054
TRANSMIT_FREQ_RATE_1 = 2005-157T17:00:34 1.02238
TRANSMIT_FREQ_1 = 2005-157T17:33:07 7175544399.14254
TRANSMIT_FREQ_RATE_1 = 2005-157T17:33:07 0.98827
TRANSMIT_FREQ_1 = 2005-157T18:01:57 7175546108.84817
TRANSMIT_FREQ_RATE_1 = 2005-157T18:01:57 0.95097
TRANSMIT_FREQ_1 = 2005-157T18:28:34 7175547627.55415
TRANSMIT_FREQ_RATE_1 = 2005-157T18:28:34 0.91035
TRANSMIT_FREQ_1 = 2005-157T18:54:53 7175549064.99311
DATA_STOP

```

Figure D-16: TDM Example: Uplink Frequencies Only

In general practice, it is expected that Doppler, range and angle data will not be interspersed in a single TDM segment, because of issues with interpreting the meaning of certain metadata keywords, in particular, the 'DATA_QUALITY' keyword. However, the specification does not prohibit such a combination.

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-65
PARTICIPANT_2 = yyyy-nnnA
MODE = N/A
START_TIME = 2005-157T08:22:46
STOP_TIME = 2005-157T18:54:53
META_STOP

DATA_START

COMMENT this example still in progress... but see Figure 6 for the time
COMMENT being... it has downlink frequencies, range, range rate, and angles
COMMENT combined in a single TDM segment.

DATA_STOP
```

Figure D-17: TDM Example: Combined Doppler, Range, Angles

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25-X
PARTICIPANT_2 = DSS-25-Ka
PARTICIPANT_3 = yyyy-nnnA
PARTICIPANT_4 = yyyy-nnnA-beacon
MODE = N/A
START_TIME = 2005-157T08:22:46
STOP_TIME = 2005-157T18:54:53
META_STOP

DATA_START

COMMENT this example still in progress

DATA_STOP
```

Figure D-18: TDM Example: Two Uplinks

The following are some additional scenarios that are not currently considered in the example set, but could be included in later versions of the TDM:

- a) S/C-S/C crosslinks;
- b) Ground based transponder;
- c) 'DORIS';¹
- d) Arrayed downlink;²
- e) Orbital debris example;
- f) Combine radiometric types with media or meteorological data.

Keyword Coverage (still a few keywords not in examples).

Keyword
AGC
AZIMUTH_RATE add an example
CARRIER_SNR
CORRECTION_ANGLE1
CORRECTION_ANGLE2
CORRECTION_DOPPLER
CORRECTION_MEDIA
CORRECTION_TROPO_DRY
CORRECTION_TROPO_WET

¹ Note to DSB: p.621.

² Must identify the phase center.

ANNEX E

INFORMATIVE REFERENCES

(INFORMATIVE)

NOTE – Normative references are provided in 1.5.

- [E1] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVIIth Plenary Assembly*. Geneva: CCIR, 1990.
- [E2] *Radio Metric and Orbit Data*. Recommendation for Space Data System Standards, CCSDS 501.0-B-1-S. Historical Recommendation. Issue 1-S. Washington, D.C.: CCSDS, January 1987.
- [E3] *XML Schema Part 2: Datatypes*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.
- [E4] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-1985. New York: IEEE, 1985.
- [E5] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.
- [E6] *The Application of CCSDS Protocols to Secure Systems*. Report Concerning Space Data System Standards, CCSDS 350.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, March 1999.
- [E7] *Attitude Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 504.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.
- [E8] Catherine L. Thornton and James S. Border. *Radiometric Tracking Techniques for Deep-Space Navigation*. JPL Deep Space Communications and Navigation Series. Hoboken, New Jersey: Wiley, 2003.
- [E9] *XML Specification for Navigation Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 505.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.
- [E10] Theodore D. Moyer. *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*. JPL Deep Space Communications and Navigation Series. Hoboken, New Jersey: Wiley, 2003.